UNIVERSITÉ DE SHERBROOKE

Measuring the Level of Supply Chain Robustness During Construction Mega-Projects

par

Dany Julien

Thèse présentée à l'École de gestion

comme exigence partielle
du doctorat en administration (DBA)
offert conjointement par l'Université de Sherbrooke
et l'Université du Québec à Trois-Rivières

Avril 2020

UNIVERSITÉ DU QUÉBEC

THÈSE PRÉSENTÉE À L'UNIVERSITÉ
DU QUÉBEC À TROIS-RIVIÈRES

COMME EXIGENCE PATIELLE
DU DOCTORAT EN ADMINISTRATION (DBA)
OFFERT CONJOINTEMENT
PAR L'UNIVERSITÉ DU QUÉBEC À TROIS-RIVIÈRES
ET L'UNIVERSITÉ DE SHERBROOKE

PAR
DANY JULIEN

MEASURING THE LEVEL OF SUPPLY CHAIN ROBUSTNESS DURING CONSTRUCTION MEGA-PROJECTS

AVRIL 2020

UNIVERSITÉ DE SHERBROOKE

École de gestion

Measuring the Level of Supply Chain Robustness During Construction Mega-Projects

Dany Julien

Cette thèse a été évaluée par un jury composé des personnes suivantes :

Daniel Chamberland-Tremblay, Ph.D.	Président du jury, UdeS
Claude Caron, Ph.D.	Directeur de recherche, UdeS
Éliane Moreau, Ph.D.	Représentante, UQTR
Élisa Gagnon, Ph.D.	Examinatrice externe, Bishop’s University
Hans Picard, Ph.D.	Représentant du milieu de pratique, MIT

UNIVERSITÉ DU QUÉBEC À TROIS-RIVIÈRES

École de gestion

Measuring the Level of Supply Chain Robustness During Construction Mega-Projects

Dany Julien

Cette thèse a été évaluée par un jury composé des personnes suivantes :

Daniel Chamberland-Tremblay, Ph.D.	Président du jury, UdeS
Claude Caron, Ph.D.	Directeur de recherche, UdeS
Éliane Moreau, Ph.D.	Représentante, UQTR
Élisa Moreau, Ph.D.	Examinatrice externe, Bishop’s University
Hans Picard, Ph.D.	Représentant du milieu de pratique, MIT

Summary

The construction industry operates in a complex, dynamic and human-driven environment that are full of challenges and uniqueness. The construction industry also acts as an important economic motor amongst many industrial countries and their GDP ratios. Nonetheless, too often construction mega-projects are observed in these industrial countries as being completed late in time and over budget in costs, thus affecting directly their GDPs. Canada is not immune from these problems and complexities.

As trade barriers fall and new global agreements come into effect, the Canadian construction companies are now facing a new reality where global competitors are being able to bid within the Canadian markets, which were once protected by these trade barriers. Further to this global threat, there is also evidence in various studies, that the Canadian construction industry is inefficient and under-performing, subsequently decreasing the ability of Canadian construction companies.

In investigating these problems in construction literatures, it is understood there is no holistic model, nor any solid-proof framework, nor a single theory that can accurately measure performances and productivities during mega-projects' activities. Furthermore, the researcher did not come across during its review of literature, to a model which consider measuring performance and productivity throughout each phase of construction project management. In fact, several construction models too often attempt to home their findings on measuring geo-locations for materials at construction sites or providing some complex algorithm formulas, which are not adapted to be readily used by the industry's stakeholders.

Overall, the literature agrees over many reasons for these costs' overruns and late deliveries during mega-projects. For one, the construction industry is generally viewed as technologically stagnant and is considered slow to adopt management information technologies. In addition, the construction industry is not willing to

provide up-front investment for new technologies that will be used in short-period projects. Other reasons stem from poor planning organisation, performance management, stagnation in labour quality, etc., which lead to low productivity in construction.

Other authors believe in solving this problematic by reshaping regulations against or for unions, or rethinking the design methodologies with more prefabrication, or infusing automated technologies at job sites and re-skills workers with more automated systems. Other studies prone the use of geolocation devices such a RFID as a solution to help reducing costs and deliver project on time.

The objectives of this research are to propose an artifact or design (Construction Performance & Productivity Model - CPPM), which is to be used during construction mega-projects with the intent to reduce the managerial problematic of cost overruns and late deliveries. The model envisions the following objectives:

1. The implementation of a supply chain approach as the basic framework for the proposed model;

2. By providing real-time measurement at construction site, which will help forecasting projects' costs and delivery scheduled throughout the construction phases;

3. By offering a construction model that is friendly to use by construction stakeholders; and provide performance attributes and metrics, which are useful to construction specialists;

4. By providing performance attributes and KPI metrics, which are useful to the industry, in terms of engineering (E), procurement (P) and construction management (CM) activities;

5. By offering a model that covers all phases and aspects of construction mega-projects, beginning with conceptual, front-end planning, detailed-engineering and ending by the construction.

6. The model must adapt to several types of construction contracts, such as time & materials (cost plus) and lump sum contracts;

Hence, these objectives are line with the managerial problems of cost overruns and late deliveries. In order to validate the value of this proposed model, the researcher put forward the following research question into two sections:

- While integrating a supply chain framework processes (end-to-end) in construction project management, which performance attributes and metrics are essential to a model having the objective of attenuating the managerial problems of cost overruns and late deliveries, while considering four (4) types of construction contracts?

- Subsequently, in this proposed supply chain-driven model, is there a certain dominance of performance attributes and metrics belonging more to engineering, procurement or construction activities?

The methodologies for this research began with the review of literature amongst journals specializing in supply chain management for manufacturing and construction, along with reading other articles in project management related to mega-projects and finishing with journals in management information systems. Then, after establishing the objectives and questions for this research, the researcher went on to validate the problematic by spending four years in two different residences. At first, a participant observation was conducted at an engineering firm, to be followed by a research action at a nuclear mine project. Following these two residences and further reviewing the theoretical literatures related to mega-project management, the researcher went ahead and conducted several semi-structured interviews followed by a final survey before analyzing the quantitative and qualitative results of this doctoral research.

Consequently, the research over the years evolved from the freedom of adopting various theories and methodologies of research, in order to steer forward with one vision – being able to attenuate mega-projects' cost overruns and late deliveries. The approach of the Design-Science Research (DSR) was selected for this research because it espouses the academic freedom both science and real-life environment. In fact, the DSR approach doesn't solely rely on proving one holistic theory but rather relies on a series of kernel theories, supporting each other's toward common research objectives.

Henceforth, the strength of DSR was used in this research for recognizing the contribution of both design (artifact) and science (kernel theories) in a construction environment.

Through the methodologies presented above, and the Design-Science Research's approach, the researcher believes the proposed model (CPPM) met the research objectives and managerial questions. The proposed model started from the basis of the SCOR Model, which is a supply chain framework model frequently used in manufacturing. The SCOR Model was first enriched with KPIs pertaining to construction project management, then reduced to a more convivial model presented as the Construction Performance & Productivity Model (CPPM). The researcher believes the CPPM has permitted the science to progress with this proposed model by offering the following advancement:

1. The research has identified seven (7) constructs which are related to construction project management. These constructs are correspondingly supported by prolonged period observations during Participant Observation and Action Research methodologies; and as well as a series of remarks recorded during the semi-structured interviews and survey;

2. The model is reinforced by a Participant Observation that provides a grounded picture of all four phases of construction project management, in one hand, of the dominance in engineering and construction activities, and on the other hand, the low level of activities related to supply chain metrics;

3. The model is reinforced by an Action Research that provides a true picture of the construction activities, which demonstrated a consistent level of material management's inaccuracies during the construction phase;

4. The strength of the model covers and applied to all phases of construction project management, starting at the conceptual phase, followed by the front-end planning, the detailed engineering, finally the construction/closed-out phase;

5. The model is validated by two residences and in accordance with the Design Research approach, through a series of principles, processes, evaluation, contribution and justification knowledge;

6. The proposed model, first enriched from SCOR, then simplified into CPPM, offers an originality and inventiveness, which is different from the ones found in construction or manufacturing literatures;

7. The model displayed the artful ability to return to a situation, re-apply itself, and discover aspects of the situation that affected the final design. In a sense, it offers a mid-range theory approach, that remains temporary and flexible to change(s) for ending into a better model.

The research's results demonstrated the most robust performance attributes and metrics (Level I, II, and III) in the model were, first the EPCM Agility, followed by Project Controls and lastly, Procurement Reliability.

The researcher concluded some limitations to its proposed model (CPPM). The Construction Performance & Productivity Model has achieved a level of consistency for only the construction site it was tested to. This limitation, where the Construction Performance & Productivity Model was not tested at other construction sites, is simply due to time restriction for the research. So, the CPPM by itself is still immature. Another limitation brought forward was the range of the Likert scale could have been increased from 1-5 to 1-10. Finally, the DSR literature presents various methods of validating a research, making it subjective to any authors' preferences.

On the other hand, the proposed model (CPPM) offers many opportunities to other scientists to further the model's validity, confidence and consistency, by testing it in different sites and sub-sectors of the construction industry. Opportunities also exist in conducting researches in all phases of construction project management with the proposed model. There are also opportunities in integrating business intelligence tools within the CPPM. Integration of academia and field researchers must be increased in order to understand the ground managerial problematic of cost overruns and late deliveries. This type of BI tool integration offers great opportunities for the field of construction project management. Finally, the author of this thesis incites more researchers to use this proposed model in different construction mega-project settings, such as mining, oil & gas and civil mega-projects.

Synthèse

INTRODUCTION À L'INDUSTRIE DE LA CONSTRUCTION

Les grands projets de construction dans les pays industrialisés sont souvent la critique de débordement de coûts et de retards de livraison. Que ce soit l'Europe, les États-Unis ou le Canada, les pays industrialisés démontrent tous des tendances similaires d'inefficacité, dont 98% des grands projets font face à des débordements de coûts et 77% d'entre eux démontrent des retards de livraison (Changali *et al., 2015)*. La productivité dans le secteur de la construction à travers les pays industrialisés demeure constante depuis plus de 70 ans, tandis que les autres secteurs industriels comme le manufacturier, l'agriculture et celui du marché du détail démontrent tous des croissances depuis le début des années 80. Au Canada, la productivité reliée à la construction démontre la même tendance.

Malgré le manque d'efficacité dans le secteur de la construction, cette industrie offre des opportunités d'amélioration estimées à plus de 1,600 milliards à l'échelle mondiale.

LA PROBLÉMATIQUE MANAGÉRIALE

Cette thèse fait état d'une problématique managériale dans laquelle l'industrie de la construction complète ses mégaprojets, en général, avec des dépassements de coûts et des retards de livraison. La littérature en gestion de la construction chemine sur plusieurs approches qui tentent de résoudre cette problématique managériale évoquée dans cette thèse. Malgré le fait qu'une solution ne peut être holistique en elle-même, la littérature propose plusieurs approches et solutions afin de résoudre cette problématique.

Par exemple, la littérature explore des cheminements potentiels comme l'intégration des systèmes d'information lors de la mise en œuvre de grands chantiers; ou l'application de nouvelles normes de travail et de régie contractuelle portant vers la valorisation de syndicats progressistes. Il y a aussi les études qui se penchent vers une plus grande emphase sur la construction modulaire hors-chantier; ou celles qui suggèrent de revoir l'apprentissage académique des métiers de construction.

Parmi la littérature dans le domaine de la gestion en construction, on y retrouve aussi dans la littérature, plusieurs modèles mathématiques, complexe en soit, mais encombrant et non-convivial aux yeux des gestionnaires de Finalement, on y retrouve plusieurs recherches de traçabilité, dont les plus notables tentent souvent de mesurer la géolocalisation des matériaux, sans comprendre les processus mis en place, liés à leur échec ou succès de leur traçabilité. Il vaut donc mieux encadrer l'intégration d'une meilleure chaîne d'approvisionnement lors de la mise en œuvre de mégaprojets (Changali *et al. (2015)*. De plus, l'auteur de cette thèse n'a pas rencontré de modèle mesurant la performance et la productivité d'activités qui couvrent toutes les phases de la gestion de projet de construction, en commençant par la phase conceptuelle, suivie par la phase de planification (*Front-End Planning*) et celle de l'ingénierie détaillée (*Detailed-Engineering*), pour aboutir par la phase de construction.

De ce fait, le nombre d'articles retrouvés en littérature sous la rubrique de la gestion en construction ou celle de la gestion de mégaprojet, et qui considère le processus de la chaîne d'approvisionnement, sont pratiquement inexistants, tout particulièrement durant les phases conceptuelles, de planification et de construction. En cohésion avec la littérature courante et le manque de connaissance relié à la chaîne d'approvisionnement durant les mégaprojets, l'auteur de cette thèse a donc décidé de cibler l'approche d'un cadre opératoire de type chaîne d'approvisionnement (*supply chain)* qui est intégré dans un modèle lors d'exécution de mégaprojets.

OBJECTIFS DE LA RECHERCHE

Les principaux objectifs de cette recherche sont basés sur le fait que la plupart des modèles de construction examinés dans la littérature ne symbolisent pas les phases ciblées lors de mégaprojets. Donc, les objectifs de cette recherche veulent avant tout, établir l'élaboration d'un modèle de gestion lors de mégaprojets en construction qui va chercher à atténuer la problématique managériale présentée dans cette thèse. Les objectifs de cette recherche sont basés sur la mise en œuvre d'un modèle de mégaprojets comme suit:

1. Basé sur un cadre opératoire qui est typique à la philosophie "*end-to-end*" d'une chaîne d'approvisionnement (*supply chain)*;

2. Doit être capable de fournir des facteurs clés de succès qui mesure en temps réel les activités sur les sites de construction, ce qui aidera à atténuer les coûts des projets et les livraisons prévues tout au long des phases de construction;

3. Doit être convivial à utiliser par les parties prenantes durant les mégaprojets;

4. Doit avoir des attributs de performance et des facteurs clés de succès "EPCM", qui aideront à comprendre les activités d'ingénierie (E), d'approvisionnement (P) et de la construction (CM);

5. Combler les lacunes de la littérature en matière de gestion de mégaprojets, en proposant un modèle couvrant toutes les phases des mégaprojets et être en mesure de réagir à différents types de contrats.

Par conséquent, cette recherche concentre ses objectifs sur la conception d'un artefact (Modèle de Performance et de Productivité de la Construction) appelé dans le texte "*Construction Performance & Productivity Model (CPPM*)". Ce modèle analyse les activités essentielles des achats et de l'ingénierie, et celles de la construction, du contrôle des coûts, et de la complexité des fournisseurs (hors-chantier) et de la gestion des employés lors des mégaprojets.

Au-delà de la couverture de toutes les phases de mégaprojets, le cadre du modèle repose, en premier lieu, sur l'intégration des processus de la chaîne d'approvisionnement. Finalement, le modèle offre une souplesse nécessaire à l'adaptation de divers types de contrats.

QUESTION DE LA RECHERCHE

En intégrant les processus de la chaîne d'approvisionnement (end-to-end) dans un modèle de la gestion de mégaprojets en construction, la question de recherche repose sur deux volets:

1. Quels sont les attributs de performance et facteurs clés de succès essentiels à l'efficacité du modèle de gestion de mégaprojets dont l'objectif est l'atténuation de la problématique managériale, tout en considérant quatre types de contrats de construction?

2. Est-ce qu'il y a une prédominance de certains attributs de performance et des facteurs clés qui sont proposés à la question 1^0, appartenant soit à ceux de l'ingénierie, de la chaîne d'approvisionnement ou de la construction?

Afin de répondre à la question de recherche et rencontrer ses objectifs, l'auteur de cette thèse à cibler pour sa méthodologie la cadre opératoire offert par celui de la recherche design-science (*Design Science Research*).

MÉTHODOLOGIE

À part d'utiliser la recherche design-science comme sa principale méthodologie, l'auteur a aussi fait appel à une approche pragmatique avec des revues de littérature en gestion d'approvisionnement, en gestion de projet, en gestion de construction et en système d'information; suivi par deux résidences dont une observation participative dans une firme d'ingénierie et d'une recherche action lors d'un mégaprojet dans une mine nucléaire. Finalement, à la suite des entrevues semi-structurées et d'un sondage final, les résultats d'analyses quantitatives et qualitatives ont aidé à l'élaboration du modèle "*CPPM*".

Cette série de méthodologies a permis à l'auteur de s'immerger et d'explorer la vie réelle des acteurs principaux de l'industrie de la construction et de mieux comprendre les difficultés que fait face cette industrie. Bien que les auteurs Baarts (2009); Thiel

(2013) et Shipton *et al*. (2014) pensent que la littérature de construction devrait s’appuyer sur des méthodes ethnographiques permettant de mieux comprendre les expériences et pratiques vécues, le doctorant n’a pas rencontré d’études dans la littérature où les chercheurs ont été eux-mêmes impliqués pendant une période prolongée et dans un environnement réel dont ceux des mégaprojets.

Donc, afin de mieux comprendre les contextes réels des mégaprojets, cette recherche s’appuie sur une approche relativiste, sur l’ontologie du constructivisme, sur l’épistémologie du subjectivisme et la souplesse du pluralisme, ainsi que sur l’approche de recherche en design science.

CADRE OPÉRATOIRE

Le cadre opératoire de cette recherche passe donc du théorique au pratique à plusieurs reprises. La première phase de ce cadre est basée sur la revue de littérature. Tel que mentionné, l’auteur de cette thèse a amorcé une revue de littérature en gestion d’approvisionnement dont un segment sur le manufacturier et un sur la construction, puis une revue sur les pratiques en gestion de projet et en gestion de construction, pour finaliser avec une revue sur l’acceptabilité des systèmes d’information et de la technologie en “*supply chain”*. À partir de ces revues de littérature, l’auteur a aussi ciblé le besoin de bien comprendre l’intégration de la chaîne d’approvisionnement lors de mégaprojets de construction.

La deuxième phase du cadre a permis à l’auteur de passer à l’aspect pratique dont l’exécution de deux résidences sur des chantiers de mégaprojets. Durant la période 2013-2014, l’auteur à l’aide d’observations participatives et de son emploi corporatif, a pu entreprendre l’étude des activités de gestion de mégaprojets, en commençant par la phase conceptuelle, suivi de la phase de planning (*Front-End*) et celle de l’ingénierie détaillée (*Detailed Engineering)*, pour se terminer par la phase exécutive de la construction. L’objectif de ces observations fut d’analyser le nombre d’activités de type “*supply chain”* mises en place lors des phases de mégaprojets. La deuxième méthode de collecte de données a été entreprise entre 2015 et 2016, lors de la construction d'un mégaprojet minier. Durant cette période, le doctorant, à l'aide de l'approche recherche-action et de son emploi comme "*Material Manager*", a pris connaissance de la problématique des surplus d'inventaires sur le chantier. L'objectif de cette recherche-action fut d'analyser le niveau de qualité de contrôle et des prises d'inventaires qui y étaient mis en place par le maître-contracteur et les superintendants.

Les deux résidences ont permis au doctorant de passer plusieurs années à l'intérieur d'une société d'ingénierie et sur un mégaprojet de construction, tout en observant et effectuant des recherches sur la gestion de mégaprojets de construction, et plus particulièrement sur les processus de la chaîne d'approvisionnement mis en place. Au cours de ces deux résidences, le chercheur a observé sept constats identifiés comme suit :

1. Les objectifs économiques divergent parmi les différents intervenants dans les mégaprojets de construction;

2. La chaîne d'approvisionnement, telle que connue dans le milieu manufacturier (*end-to-end*) est fragmentée dans le secteur de la construction;

3. Les processus de gestion de projets et les analyses de productivités indiquent un statu quo parmi les décideurs de mégaprojets;

4. Il y a une certaine homogénéité dans la pratique de la gestion de mégaprojets;

5. Le "*macro-reporting*" des données lors de mégaprojets sont courants et les analyses BI sont inexistantes;

6. Les changements apportés aux designs sont toujours vus comme étant coûteux;

7. L'incertitude dans les mégaprojets est commune et acceptée par tous les intervenants comme un fait acquis.

À part de ces sept constats, l'auteur de cette thèse a aussi noté des comportements organisationnels, dépendamment des types de contrats (temps et matériaux ou montant forfaitaire) et des intervenants du milieu (donneurs d'ouvrage, contracteurs, firmes d'ingénierie, syndicats et consultants).

Une fois les deux résidences étant complétées, l'auteur est revenu une fois de plus sur sa recherche théorique pour débuter sa troisième phase de ce cadre opératoire. Conscient du contexte théorique, où l'industrie de la construction a une importance significative sur le produit intérieur brut (Pib) dans les pays industrialisés, et qu'il est évident que chaque gain en pourcentage d'efficacité lors d'exécution de mégaprojets a un effet important pour ces pays; l'auteur a donc entrepris une deuxième revue théorique de type théorie "*kernel"*, se focalisant (a) en premier lieu sur une approche économique par une première revue sur le "*Resources-Based View"* et celle de la théorie des capacités dynamiques, suivi (b) d'une deuxième revue sur l'adaptation des systèmes d'information et finaliser (c) avec une revue de théories organisationnelles, dont la théorie du co-alignement, la théorie de la contingence, et en dernier lieu, la théorie de la structuration de la dualité. Les théories "*kernels"*, qui ont été sélectionnées a permis à l'auteur une flexibilité théorique, temporaire et non définitive (Boudain, 1991).

C'est aussi durant cette troisième phase du cadre opératoire que le modèle "*SCOR Model"* fut introduit. Compte tenu des lacunes dans la littérature examinant les processus d'approvisionnement durant les phases de mégaprojets, cette recherche a adopté initialement SCOR (*Supply Chain Operations Reference*) comme modèle de référence. Ce modèle a été créé par le *Supply Chain Council* aux États-Unis, pour les secteurs manufacturiers, aéronautiques, pétrochimiques et plusieurs autres secteurs industriels. Incidemment, plusieurs auteurs dans la littérature soutiennent que le modèle SCOR constitue également l'une des meilleures options pour mesurer les processus de "*supply chain*" du début à la fin, lors de mégaprojets de construction. Cependant, de nombreux auteurs tels que Cheng *et al*. (2010); Gunasekaran *et al.* (2004) et Johansson *et al*. (2011) ont soutenu que le modèle SCOR, en lui-même, devait être adapté pour mieux prendre en compte les complexités de l'industrie de la construction. Le modèle SCOR, comprenant des attributs de performance et environ 250 facteurs clés a donc été enrichi avec des attributs et facteurs clés qui représentent les phases de mégaprojets, pour atteindre environ 366 facteurs clés. Le modèle couvre des fonctionnalités telles que l'approvisionnement, l'ingénierie, la construction, le contrôle des coûts, la gestion des travailleurs sur les chantiers ainsi que la complexité hors-chantier.

Une fois le modèle enrichi, l'auteur a passé à la quatrième phase du cadre opératoire, dont l'aspect pratique qui consistait d'entrevues semi-structurées et d'un sondage avec des gestionnaires seniors, ayant plusieurs années d'expériences en exécution de mégaprojets. À la suite des entrevues semi-structurées et d'un sondage, ce modèle enrichi a été réduit à moins de cinq attributs de performance et 86 facteurs clés, tous étant reliés à la gestion de mégaprojets. Cette réduction du modèle enrichi est la base de l'élaboration de l'artefact de cette recherche nommé "*CPPM-Construction Performance & Productivity Model"*, qui intègre les attributs de performance et les facteurs de succès de la chaîne d'approvisionnement aux activités de la gestion de projet.

ARTEFACT

Cet artefact, là encore, n'est pas une solution globale aux problèmes de gestion auxquels font face les mégaprojets, mais l'artefact est présenté comme l'une des nombreuses solutions potentielles pouvant aider à résoudre les problèmes managériaux reliés aux dépassements de coûts et aux retards de livraison. Par conséquence, l'artefact est aussi temporaire et non-défini. Donc, en utilisant l'approche kernels, il est à penser que l'abrégé du modèle (*CPPM*) proposé dans cette thèse, sera utilisé dans d'autres projets et s'améliorera ultérieurement, avec l'ajout ou la suppression d'éléments théoriques. L'auteur de cette thèse croit que cette approche servira à mieux comprendre la problématique managériale des mégaprojets.

RÉSULTATS

Sommairement, les sept constats notés lors d'observations participatives (*Participation Observation*) et de la recherche-action (*Action Research*) sont supportés par des annotations obtenues lors d'entrevues semi-structurées.

Le résultat de l'observation participative a été en premier lieu, la création d'un organigramme sur les flux d'activités lors de gestion de mégaprojets, en commençant par la conception et se terminant par la phase de la construction. En conclusion, le nombre d'activités qui faisaient référence à la chaîne d'approvisionnement dans l'organigramme des flux d'activités lors de gestion de mégaprojets n'était que de 27%. Les phases d'ingénierie et de construction ont démontré les niveaux d'activités les plus élevés de la chaîne d'approvisionnement, avec 46% et 35% respectivement. Étonnamment, la planification initiale et la phase hybride (planification initiale et ingénierie détaillée) illustrent l'absence de considération relative à la chaîne d'approvisionnement lors de la construction de mégaprojets. Cependant, les résultats démontrent l'importance de la chaîne d'approvisionnement durant les deux dernières phases de mégaprojets.

Au point de vue de la recherche-action, le chercheur conclut que le maître-entrepreneur avait sans aucun doute échoué dans sa tentative de garder ses inventaires à jour. En comparaison aux inventaires des industries manufacturières ou d'autres secteurs industriels qui ciblent des niveaux de précision, tel six sigma (99,99966% - erreur de 0,00034%,), il est aisé d'affirmer que les départements électriques et mécaniques du maître-entrepreneur, ont échoué, sans équivoque, dans leurs tâches de garder les stocks à jour avec des performance d'inexactitude (imprécision) aussi forte que 82% et 37% respectivement. Ces échecs de maintenir un niveau de précision d'inventaire adéquat, sont des raisons de réaffirmer que la chaîne d'approvisionnement dans l'industrie de la construction est sévèrement fragmentée et dysfonctionnelle.

Ce qui a trait aux entrevues semi-structurées et les sondages, ils ont permis d'identifier quels étaient les attributs et les facteurs clés de performance dominant parmi quatre (4) types de contrats en construction. Les trois attributs de performance dominant ont été attribués à l'*EPCM Agility,* la fiabilité des achats et l'attribut du contrôle des coûts de projet.

Les résultats obtenus supportent les cultures courantes qui règnent dans les grands chantiers, où les métriques d'ingénierie et de construction sont vues comme nettement plus importantes que les métriques du "*supply chain*".

CONCLUSION

Le modèle SCOR a pu être enrichi et simplifié dans un modèle de mégaprojet (*CPPM*) qui rencontre les objectifs de cette recherche. Le modèle "*CPPM*" est le résultat d'une observation participative, d'une recherche-action, d'entrevues semi-structurées et d'un sondage, tous menés par des experts dans la gestion de mégaprojets. Le modèle "*CPPM*" est convivial aux intervenants du milieu, qui sont libre de choisir leur niveau de robustesse, selon le type de contrat.

Par ces faits, le modèle "*CPPM*" est une amélioration (enrichi, puis simplifié) à celui de modèle "*SCOR*". Le modèle "*CPPM*", à l'opposé de "*SCOR*", couvre toutes les phases de gestion de mégaprojets de construction.

En conclusion, malgré le fait d'avoir implanté un modèle avec un cadre opératoire de type "*supply chain*", les attributs et facteurs clés (métriques) reliés à l'ingénierie et la construction demeurent dominant dans le modèle "*CPPM*". Donc, il semble apparent que d'établir une chaîne d'approvisionnement (*supply chain*) telle que l'on retrouve dans les industries manufacturières n'est pas prioritaire à l'heure actuelle dans l'industrie de la construction.

VALIDATION

L'auteur de cette thèse conclut la validation du modèle de performance et de productivité de la construction (*CPPM*), car il atteint son utilité environnementale attendue, alors que la justification de l'artefact prouve qu'il sera utile pour résoudre des problèmes ou à apporter des améliorations dans la façon de gérer des mégaprojets. L'auteur de cette thèse a également conclu que le modèle constitue un solide remplacement comparativement au modèle "*SCOR"*, qui ne couvre surtout pas les deux phases les plus dynamiques et les plus coûteuses de la gestion de projet de construction, soit celle de l'ingénierie détaillée et celle de la construction.

L'auteur de cette thèse valide également que la conception de son artefact (design) a fait la promotion à l'apport des connaissances dans l'industrie de la construction. Cet apport est basé sur la base d'un engagement prolongé, d'observations persistantes, de ses critères d'originalité, sa justification de nouvelle connaissance, d'inventivité et d'objectivité, et subséquemment sa validité interne.

Enfin, l'auteur de cette thèse reconnaît que la conception du modèle proposé dans cette thèse, présente certaines limitations. L'auteur conclut que l'artefact est fiable que pour le site de construction sur lequel il a été appliqué. Malheureusement, la recherche n'a pas pu être répétée dans d'autres sites de construction due à la contrainte de temps pour effectuer un doctorat. De plus, l'auteur reconnait que les méthodes de validation de la recherche design-science demeurent subjectives aux yeux des chercheurs qui utilisent cette recherche.

OPPORTUNITÉS DE RECHERCHE

Cependant, ces limitations énumérées ci-hauts offre des opportunités ultérieures de recherche pour d'autres chercheurs, notamment faire avancer le design du modèle et d'introduire d'autres théories kernels afin de solidifier la théorie "*mid-range"* de l'artefact proposé dans cette thèse. L'auteur souhaite voir des chercheurs mener plus de recherches qualitatives et quantitatives qui couvrent toutes les phases de mégaprojets. L'auteur aimerait améliorer le modèle "*CPPM*" en le testant dans d'autres mégaprojets. L'industrie est en retard envers l'acceptabilité des systèmes d'information. Il y a une opportunité d'introduire des outils BI au modèle "*CPPM*". Finalement, les chercheurs en construction devraient accentuer les recherches favorisant les maillages entre praticiens et eux, afin qu'ils travaillent davantage en symbiose.

CONTRIBUTIONS

Cette thèse, selon son auteur, contribue à l'avancement dans l'industrie des mégaprojets et ses problématiques managériales, car elle rencontre quatre questions importantes énoncées par Wilson (2002):

a. Est-ce vrai? Les mégaprojets de construction marqués par des dépassements du budget et des livraisons tardives ne sont pas des nouveaux symptômes dans l'industrie canadienne. Ils sont en effet symptomatiques;

b. Est-ce nouveau? Le problème managérial exprimé dans cette thèse, dont les dépassements des coûts et les livraisons finales tardives n'ont pas été résolu depuis plus d'une cinquantaine (50) d'années;

c. Est-ce intéressant? D'après Gregor *et al.* (2013), c'est peut-être la question la plus importante des trois. De toute évidence, si la recherche n'est pas intéressante, il n'y a pas lieu de poursuivre les deux premières questions. L'auteur de cette thèse croit que ce sujet est pertinent et très intéressant, compte tenu de son importance économique.

d. Aurait-elle une contribution industrielle? Cette thèse démontre que l'intégration de processus de la chaîne d'approvisionnement durant l'exécution de mégaprojets de construction aurait un intérêt substantiel pour l'industrie, comme ceux de l'automobile, l'agriculture et autres secteurs.

Résumé

Trop souvent, les mégaprojets sont complétés en retard et dépassent les budgets prévus. Néanmoins, il n'existe toujours pas de modèle unique, ni de cadre opératoire, ni de théorie holistique pouvant mesurer les performances et les productivités des divers activités lors de mégaprojets de construction. Une solution proposée par l'auteur de cette thèse est la formulation d'un artefact ou d'un design, appelé modèle de performance et de productivité de la construction (*CPPM*), qui intègre un cadre opératoire à partir des processus de la chaîne d'approvisionnement.

Le modèle de performance et de productivité de la construction fait face à la problématique managériale avec la vision de développer une conception d'attributs et de facteurs clés qui rendrait l'industrie de la construction canadienne plus compétitive. Le cadre du modèle repose sur une approche de chaîne d'approvisionnement, et fournit des facteurs clés de succès en temps réel avec des attributs de performance et des mesures couvrant toutes les phases des mégaprojets.

La recherche aux fils des ans a su évoluer grâce à la liberté d'adopter diverses méthodologies et d'étudier plusieurs théories. L'approche de la recherche en design-sciences a donc été choisie parce qu'elle englobe cette liberté académique dans le design managérial, l'approche théorique et l'environnement réel des mégaprojets.

Le modèle "*CPPM*" a révélé que les attributs de performance et les facteurs clés de succès prédominant à l'artefact, étaient ceux reliés aux "*EPCM Agility"*, suivis des contrôles de coûts et ceux de la fiabilité des achats.

L'auteur de cette thèse estime que la recherche entreprit lors de son doctorat a permis à la science de progresser. Cette thèse s'appuie sur ses sept constats liés à la gestion de mégaprojets, renforcée par quatre ans d'observations avec des experts de l'industrie, des entrevues semi-structurées et sondage, de même que la conception

d'un modèle "*CPPM*" qui couvre toutes les phases et activités dans la gestion de mégaprojets.

L'auteur a aussi établi un modèle qui est validé par une série de principes, de processus, d'évaluation, de contribution et de justification des connaissances, ainsi que l'originalité et l'inventivité d'un modèle qui est unique et novateur dans la littérature de la gestion de construction.

Enfin, l'auteur conclut que l'artefact a atteint un niveau de cohérence que pour le chantier de construction sur lequel il a seulement été testé. Comprenant les limites du modèle, cette recherche offre à d'autres chercheurs l'occasion de renforcer ultérieurement la validité du modèle en le testant sur différents sites de construction.

Mots clés

Approvisionnement (*Procurement*), Chaîne d'approvisionnement (*Supply Chain*), EPCM (*Engineering, Procurement, Construction Management*), Facteurs clés de succès (*Key Performance Indicators*), Gestion de construction (*Construction Management*), Gestion de projet (*Project Management*), Ingénierie (*Engineering*), Performance, Productivité (*Productivity*), Robustesse (*Robustness*).

Abstract

Too often mega-projects are completed late and over budget. Nevertheless, there is no holistic model, nor any solid-proof framework, nor theories which measures performance and productivity pertaining to the construction activities. One solution proposed by the researcher, is the formulation of an artifact or design, known as the Construction Performance & Productivity Model (CPPM), which integrates a supply chain framework.

The Construction Performance & Productivity Model seeks to attenuate the managerial problematic in the industry with the vision to develop a design that would make the Canadian construction industry more competitive. The framework of the model has a supply chain approach, provides real-time measurement with performance attributes and metrics that are pertinent to the construction industry. It is also friendly to users and covers all phases of construction mega-projects.

The research over the years evolved from the freedom of adopting various methodologies and theories. The paradigm of Design-Science Research (DSR) was selected because it espouses this academic freedom in design, science and real-life environment.

Through a Participant Observation (engineering phases) and Action Research (construction activities), using the SCOR Model as its base, enriched and minimised through a series of semi-structures interviews and one survey, the research found the most important performance attributes and metrics that performed best in the model (CPPM) were the ones belonging to the categories of EPCM Agility, followed by Project Controls and Procurement Reliability.

The researcher believes this doctoral thesis has permitted the science to progress because its model (CPPM) relates its seven (7) constructs to megaprojects, reinforced by four (4) years of observations, is validated through a series of principles, processes,

evaluation, contribution and justification knowledge. Moreover, the model's originality and inventiveness are different from the ones found in construction literature.

Finally, the researcher concludes the CPPM has achieved a level of consistency for the construction site it was only tested to it. Understanding the model's limitations, this research offer opportunities to other scientists to further the model validity by testing it in different construction sites.

Keywords

Construction Management, Key Performance Indicator, Engineering, EPCM (Engineering, Procurement, Construction Management), Performance, Procurement, Productivity, Project Management, Robustness, Supply Chain.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ABC: Activity-Based-Cost
ABSRM: Agent-Based Systems Reference model
Acfas: Association canadienne-française pour l'avancement des sciences
APC: Annual Production Growth
Auto-ID: Auto-Identification
AWP/WFP: Advanced Work Packaging / Work Face Planning
BI: Business Intelligence
BOM: Bill of Materials
CAD: Computer Aid Design program
CAD: Canadian Dollar
CAPEX: Capital Expenditure
CPPM: Construction Performance & Productivity Model
CII: Construction Industry Institute
CMT: Construction Management Team
CO: Change Orders
COAA: Construction Owner Association of Alberta
CRM: Customer Relationship Management
CPFR: Collaborative Planning, Forecasting and Replenishment model
CPPM: Construction Performance & Productivity Measurement
CWP: Construction Work Package
DB: Design Built
DBA: Doctorate of Business Administration
DC: Dynamic Capability Approach
EDRM: Electronic Discovery Reference model
E&I: Electrical & Instrumentation
EOQ: Economic Order Quantity
EPC: Engineering, Procurement, Construction
EPCM: Engineering, Procurement, Construction, Management
ERP: Enterprise Resources Planning
ETA: Estimated Time of Arrival
EWP: Engineering Work Package
FIWP: Field Installation Work Package
GDP: Gross Domestic Product
GPS: Geographical Positioning System
IDEF: Integration Definition model
IFB: Instructions for Bidders
IFC: Instructions for Construction
ISCM: Integrated Supply Chain Management
IS: Information Systems
IT: Information Technology
ITS: Intelligence Transportation System
JIT: Just-In-Time
KB: Knowledge Base

KPI:	Key Performance Indicators
LEM:	Labor, Equipment, Material
LS:	Lump Sump
MIS :	Management Information System
MPPC:	Modèle de performance et productivité en construction
MPS:	Master Plan Services
MRP:	Material Requirement Planning
MTO:	Materials Take-Off list
NCR:	Non-Conformity Report
OPEX:	Operational Expenditure
OSD:	Over, Short, Damaged
PIB:	Produit intérieur brut
PMI:	Project Management Institute
PMBOK:	Project Management Body of Knowledge
PMO:	Project Management Office
RBV:	Resources Based-View
R&D:	Research & Development
RF:	Radio Frequency
RFI:	Request for Information
RFID:	Radio Frequency Identification
ROI:	Return of Investment
RTLS:	Real-Time Location System
SCM:	Supply Chain Management
SCOR:	Supply Chain Operational Reference
SI:	Site Instruction
SOP:	Standard Operating Procedures
TMS:	Transportation Management System
T&M:	Time & Materials
US:	United States
USD:	United States Dollar
UK:	United Kingdom
VA:	Value Added Method
VRP:	Vendor Replenishment Planning
VMI:	Vendor Management Inventory
WBS:	Work Breakdown Structure
WMS:	Warehouse Management System

ACKNOWLEDGEMENT

First, I would like to thank my Director of thesis, Dr. Claude Caron for his continuous and selfless support during my D.B.A program. Without his constant encouragement and guidance, I could not have finished this dissertation. Above all, Dr. Caron have shown me the wonderful life of research, distinctive by its challenges, freedom of expression and liberty.

I would like also to thank the president of the jury, Dr. Daniel Chamberland-Tremblay and Dr. Éliane Moreau, for their valuable comments, which directed me towards the paradigm of Design-Science Research.

Dr. Hans Picard is a true gentleman, for his kind support and encouragement during my residence, and for his intriguing thoughts and ideas that we shared while living in remote mining camps. I am also very grateful to all my co-workers in construction, which endured my zillion questions over the years.

For my mother Gabrielle and my deceased father Albert, whom insisted that education was the most important gift they could provide to their children. I thank them for their encouragement, support and their investments in my educational life.

For my beautiful children Alexander, Zachary and Katya, I thank them for their comprehension of being away in remote camps or studying late nights and weekends. Most of all, I want to thank my dear wife Kristina, for her support and unconditional love and patience with my addiction to academia and works.

To all, a thousand thank you!

Dany Julien, M.Sc., DBA candidate

INTRODUCTION

The construction industry has been criticized for years for delivering projects late and over budget. Notably, this industry is fragmented and distinguished by a collection of large and small firms, with stakeholders having different objectives, while being assigned to the same project. Even though construction has changed in complexity over time, the primary objective of the industry is basically the same as it was 100 years ago: to build infrastructure, roads, schools, homes, hospitals, factories, and other businesses (Benton *et al.*, 2010). Consequently, the functionalities of construction activities, in general, haven't changes for many years, but the list of reasons why mega-projects suffer costs overruns and late deliveries remains an exhaustive one.

The first chapter introduces the managerial problems of budget overrun and late deliveries that are symptomatic to so many mega-projects. Literatures and technical journals offer several approaches that, in the opinion of the researcher, can only partially solve the managerial problems. In fact, none of the construction models in literature, which the researcher encountered through its lectures, was able to offer a holistic solution that could tackle all activities of a mega-project. Initially, the researcher noted repetitive observations that occurred during a period of observation and subsequently introduced seven (7) constructs which seem to persist in a construction environment. Finally, it is also in the first chapter where the research question and the research objectives were introduced to the readers.

The second chapter describes the theoretical context. The construction industry has an evident impact on any industrial country's economy. Billions of dollars are spent in construction projects each year in Canada. These projects include residential, commercial, industrial and mega-projects. As trade barriers are being removed by industrial countries, and transaction costs decline amongst these countries, new global markets, which were previously protected to only Canadian construction companies, are now opened globally. Consequently, foreign companies with superior production processes and cheaper labour costs are now increasing pressure on Canadian companies. In consequence, the Canadian construction companies ought to improve their performances and productivities in order to meet the new challenges brought by trade agreements.

The review of literature spanned from reading journals in material management, management information systems, supply chain management, organizational theories and project management. The researcher believes the current construction management literature is weakened by an important gap in trying to understand the end-to-end processes during mega-projects (Akyuz *et al.* (2010); Erkan (2010) and Beamon (1999). Therefore, to know whether the supply chain processes are being effectively implemented, one would have to measure the end-to-end activities in all phases of construction project management, beginning at the conceptual phase and ending by the construction and closed-out phases. The end-to-end activities sought by the researcher include procurement, engineering, construction, project controls, workers (employees) management, project complexity and project integration. Supporting the researchers' statement, Akyuz *et al.* (2010); Erkan (2010) and Beamon (1999) concluded that the current construction models suffered from the following limitations:

1. Models tend to focus on cost as the primary measure of performance. Models don't take for account all activity processes in construction;

2. Models ignore the interactions among different stakeholders' strategies and the potential influence of uncertainty which is outside management control;

3. Models ought to reflect a multiplicity of goals and outcomes, and they should also attempt to include quantitative and qualitative measures.

To fulfill this magnitude of fields and the interest in each one of them, this research opted for a kernel theory's approach. At first, the researcher was concerned with the economic impact on the construction industry and its sustainable competitiveness against global threats. Thus, at first, the review of literature investigated the Resources-Based View (RBV). The RBV was selected in order to explore if the engineering firm where the researcher was employed, possessed any kind of heterogeneous resources (i.e. supply chain processes). By possessing these advantages, this engineering firm would be able to demonstrate a superior competitive advantage in its market. While progressing in the research, the RBV was put aside to the profit of the Dynamic Capability Theory (DC Theory). This theory was judged to be better suited for a construction organization facing competitive advantage in rapidly changing external and internal environment, such as during mega-projects.

After leaving the engineering firm, the researcher quickly realized the construction industry, in general, lagged with integrating information systems within its operations. The researcher further investigated the managerial problems under the scope of the Theory of the Adoption Information Systems. Following the Theory of Adoption Information System, a fourth, fifth and sixth kernel theory were explored regarding whether a construction site can be theorized under a positivism of subjectivism segmentation. The Co-alignment theory, the Contingency Theory and the Structuration Theory of Duality suit well construction job sites, which involve complex social systems, with patterns that change over time and can be studied beyond the realm of human control with a positivism view, or by the social action with a subjective approach.

The last section of this second chapter is geared toward the SCOR (Supply Chain Operations Reference) Model. Literatures and technical journals offer several models that can partially resolve the managerial problems in construction' mega-projects. SCOR Model is one of them, however, based on the researcher' experiences in mega-project, falls shorts of covering all phases of construction project management.

The third chapter describes the operative framework, which adopted a Design-Science Research (DSR) approach. Design-Science Research represents the structuration duality, where conducting a design-only or theory-only research is not suitable either way, as neither one by itself would make an academic contribution to construction knowledge. The term Design-Science Research is by itself contradictory, and such paradoxes seem to shape the essence of this newer approach. DSR doesn't aim at analyzing a construction phenomenon, showing factual characteristics, in order to be able to identify causal relations. Instead, the design attempts to combine qualitative, quantitative and analytical modes of thinking with inventive modes focusing on developing one or several artifacts (designs), in order to solve complex, multivariate problems in elegant and unique ways (Baskerville *et al.,* 2015; Gregor *et al*., 2007; Walls *et al.* 1992). Hence, the design part of the Design-Science Research has become a very practical know-how that cannot be relegated down to an attempt to prove a theory (Baskerville *et al.,* 2015).

On the other side, for positivism researchers, science is paramount, with the primary product being a valuable theory produced (Gregor *et al*., 2007; Walls *et al.* 1992). The science-centric view, on one hand will generally recognize knowledge as collective and shared, meeting with high standards of validity and/or reliability (Glanville, 1999). Being positivist in nature, the predominant criteria for finding the truth is based in its internal validity.

Therefore, the DSR's pragmatic approach recognizes the contribution of both design and kernel theories in making true, the Design-Science Research approach. Thus, conducting a design-only or theory-only research would not be suitable in analysing managerial problems during construction mega-projects. In fact, neither the design-only nor the theory-only would seem to be able to contribute to knowledge by themselves. So, Design-Science Research addresses in its unique or innovative ways, important real-world managerial problems, like the ones express in this thesis. Having selected the DSR for this thesis, the researchers believes that it will makes a clear contribution to the real-world application of construction mega-project.

The fourth chapter focuses on the results for this research. The author used a variety of complementary methodological methods, including the review of literatures, constructs, Participation Observations and Action Research methodologies, semi-structured interviews and one survey, along with hand-written documents and notes provided by participants during the interviews.

The fourth chapter is marked by a prolonged process of observations that lasted many years. At first (2011-2014), the researcher spent time working for a global EPCM firm and was able to observe (2013-2014) through a Participant Observation methodology, the various activities in project construction management. The objective for these observations was to better understand the amount of supply chain activities that occurred during the various phases of construction mining projects. Secondly, while living in a mining camp (2014-2017), the researcher was able to conduct an Action Research over two (2) years (2015-2016) with the objective of measuring a Prime Contractor's inventory accuracies. Following a series of interviews and one survey, the researcher concluded its research by offering an artefact, known as the Construction Performance & Productivity Model (CPPM).

Th CPPM meets the process validation of a Design-Science Research by providing several validation criteria and meeting the research objectives. First, the CPPM offers four (4) basic criteria: Analysis, Design, Evaluation and Diffusion. Second, the researcher also concluded the CPPM meets four (4) DSR's principles, which are abstraction, originality, justifications and benefits. Third, the researcher validated the environmental utility of the CPPM, whereas the substantiation of the artifact provide evidence that it will be useful for solving problems or making some improvement in the construction industry.

Fourth, the researcher also concluded the Construction Performance & Productivity Model was a strong comparative replacement to the SCOR Model. Moreover, the CPPM and its kernel theories made an improvement over the current literature by describing the construction industry. The CPPM, in facts, measure project processes with performance attributes and metrics throughout that are mega-project related.

Fifth, the researcher also concludes the CPPM framework, although designed with a supply chain framework, did clearly demonstrate the engineering and construction metrics were having the strongest influences on the model.

Sixth, the researcher concludes the thesis creates justification knowledge due to the following explanations: prolonged engagement, persistent observations, originality, inventiveness, objectivity, credibility, internal validation, and design improvement. It is important to note that all conflicting statements from participants were met with valid explanations.

In addition, the researcher also concluded the design of the CPPM along with its kernel theories promoted knowledge contribution to the construction communities. Furthermore, the knowledge contribution was also supported by its prolonged engagement while employed as a T&L Manager, Material Manager and Lead Planner. Finally, the knowledge contribution is backed up by persistent observations and constructs, being original, inventiveness and objective.

In terms of its limitations, the researcher recognized the CPPM design is dependable on the construction site where it was created. Hence, the researcher concluded the CPPM has achieved a level of consistency and maturity for the site it was tested to it only. Understanding the model's limitation, this research offer opportunities to other scientists to further advanced the model's validity by testing it at different construction sites, subsequently offering a higher level of confidence and consistency for the model in the future. The researcher also understands the limitation of the DSR's validation process itself, where an author has the subjectivity of selecting which validation variables it wishes to utilise during its research.

The fifth chapter covers the end-discussion for this research. The researcher reiterates there is no holistic model, nor any solid-proof framework, nor any grand theory, or a model measuring performance and productivity throughout all phases of construction project management (conceptual, front-end planning and detailed engineering, construction and closed-out phases). Hence, there is no current construction model in the construction mega-projects, that can measure and forecast final cost and delivery time right at the onset of the project's start. The Construction Performance & Productivity Model, offered in this thesis, is by no mean the holistic answer to the managerial problems observed in the construction industry. Instead, the researcher wishes to present this artifact as one of many potential solutions that may help solving the managerial problems of budget overruns and late deliveries in mega-projects deliveries.

Overall, this doctoral thesis through its artifact (Construction Performance & Productivity Model), recognizes the contribution of both designs and theories in making true the Design-Science Research approach. The artifact shall subsequently improve over time, while other theories are added and/or removed, in order to better pursue the managerial problems in construction mega-projects.

The sixth chapter ends with conclusion and opportunities for the research. The researcher believed this doctoral thesis has permitted the science to progress with a new model, which takes for account all activities and phases of construction project management. Overall, the Construction Performance & Productivity Model was validated through a series of principles, processes, evaluation, and contribution and justification knowledge.

CPPM is a simplified model and meets all the research objectives. CPPM is the result of participants' observations, action research, semi-structured interviews and a survey with senior managers and construction experts. CPPM is friendly to use where the users can choose from three tiers. CPPM is an improvement from the SCOR Model. CPPM covers all the phases in construction mega-projects. The operational framework of the CPPM is based on supply chain operational processes and reacts to four different types of construction contracts.

The researcher believes there are several opportunities of research where more studies are needed in understanding all phases of mega-projects and their related processes. CPPM can and should be improved by testing it in other sites. The construction industry is lagging in management information systems and would benefit in integrating BI tools with models like CPPM. The managerial problems presented in this research is an important burden to countries GDP. The construction industry would benefit by the integration of practitioners and academic researchers. Finally, the researcher incites other researchers to apply the CPPM in other mega-projects so that it can improve over time.

FIRST CHAPTER
MANAGERIAL PROBLEMATIC

1.1. MANAGERIAL PROBLEMS DURING CONSTRUCTION MEGA-PROJECTS

The construction industry is often criticized for delivering projects late and over budget. According to Changali *et al.* (2015) of the consulting firm McKinsey & Co., ninety-eight (98%) percent of mega-projects suffers cost overruns and more than 77% of the mega-projects are completed with more than 40% lateness from their original schedules. The list of reasons why mega-projects suffer budget overruns and late deliveries are exhaustive. Consequently, academic literatures, journals and specialised publications state the construction industry, especially mega-projects, suffer symptomatic managerial problems on how to control costs and schedule deliveries. Examples of mega-projects that failed are abundant in history and continuous over a lengthy timeline. For instance, Flyvbjerg *et al*. (2003) illustrates the following examples:

- The Channel tunnel between England and France, opened in 1994 at a construction cost of £4.7 billion, is a case in point, with several near bankruptcies caused by construction. Financing costs that are 140% higher than those forecast, and revenues less than half of those projected;

- The cost overrun for Denver's $5 billion new international airport, opened in 1995, was close to 200% and passenger traffic in the opening year was only half of that projected;

- Operating problems with Hong Kong's new $20 billion Chek Lap Kok airport, which opened in 1998, initially caused havoc not only at the airport. The problems spread to the Hong Kong's economy as such with negative effects on growth in gross domestic product.

Canada has had also its shares of several mega-projects that went out of control. The first and probably most the famous one was the 1976 Olympic Games held in Montreal. Despite initial forecast the stadium alone would cost $134M in 1970, at the time of the opening games, it had reached $264M. It was unfinished at the start of the Olympic Games and the Big "O" was finally paid off in 2006, thirty years after the opening games at a cost of $1.6 billion dollars.

The province of Newfoundland beats out every other province in terms of mega-failures with its Muskrat Falls Hydro Project. In 2018, the hydro-power project has an unfinished tag of $12.8B, which was initially forecasted at $6.7B. Finally, they are eerie parallels in British Columbia's $9B Site-C Hydro Project and the $8.7B Keeyask Dam in Manitoba. The OPG's Darlington Nuclear Facility is also on track to follow the same path in 2018, with late deliveries and over budget.

Historically, contractors have formulated operations strategies around adversarial relationships against projects owners. Construction strategies encourage competition, where the prime contractors will shop for lower costs with their sub-contractors and enhance ultimate bargaining power against project owners (Benton *et al*., 2010). Hiring lower cost-subcontractors often don't mean better efficiencies.

The causes of mega-projects problems are often rooted to politicians. Cost overruns and lower-than-predicted revenues frequently place project viability at risk and redefine projects that were initially promoted as effective vehicles to economic growth as possible obstacles to such growth (Flyvbjerg *et al*., 2003). Mega-projects can be supported by a mixture of nationalistic government interference, private capital and development banks. Moreover, positive regional development effects, typically much touted by project promoters to gain political acceptance for their projects, repeatedly turn out to be non-measurable, insignificant or even negative (Flyvbjerg *et al*., 2003). In more antagonistic situations, many megaprojects are marked by deception, manipulation and even lies and political prostitution (Kaine, 1990; Teichroeb, 1990; Wachs, 1989; Whitworth *et al*., 1988).

At the same time, many mega-projects can suffer poor performance records in terms of economy, environment and public support due to rushing into a project without complete diligent assessment, and often in the name of a political image (Buckley, 1993).

Literatures and technical journals offer several approaches that can partially solve the managerial problematic. For instance, in the document titled Reinventing Construction: A Route to Higher Productivity, McKinsey & Co. (2017), proposed seven (7) areas that could boost construction productivity by fifty (50%) to sixty (60%) percent. They are as followed:

1. Reshape regulations;
2. Rewire contracts;
3. Rethink design through modular construction;
4. Improve procurement and supply chain;
5. Improve onsite execution, using data analytics;
6. Infuse technology and innovation, with intelligent tablets;
7. Reskill workers.

By understanding these potential routes of improvement, the researcher was also able to correlate potential solutions after spending seven (7) years in engineering and construction senior management positions. First, the researcher was able to observe through the lenses of the engineering environment the flow of activities that occurs in construction project management. By utilising a participant observation methodology, and working within the procurement department, the researcher was able to account the level of supply chain activities and integration that occur during all the project management phases.

The possibility to observe other solutions which are enumerated above, were also encountered by the researcher, while living in mining camps at various construction sites, over a period of (4) years. During the researcher's field experience, the methodology of research was changed into an action research. The objective of this action research was to understand the material inventory management process that was installed at one construction site and reports its inventory accuracies.

The results for the participant observation and the action research, were the enumeration of seven (7) construction constructs that were noted to be of a repetitive occurrence.

1.2. CONSTRUCTION CONSTRUCTS

As stated in the previous section, the researcher spent several years inside an engineering firm (2011-2014) and at various construction job sites (2014 to 2017), observing and researching on construction project management. During this period, the researcher was able to observe seven (7) repetitive constructs in the environment of engineering, procurement and construction management. They are identified as followed:

1. Diverging Objectives amongst Stakeholders;
2. Fragmented Supply Chain Processes;
3. Status Quo in the Construction Industry;
4. Homogeneity in Mega-Project Management;
5. Macro-Reporting Data during Mega-Projects;
6. Changes are Costly;
7. Uncertainty is Common.

1.2.1. Construct no. 1: Diverging Objectives amongst Stakeholders

Diverging objectives during a project is a common fact during mega-projects. Lots of individual, groups and organisation will take part in the success/failure of mega-projects. This research identified, but not limited to, five (5) stakeholders which are influential during construction of mega-projects. They are identified as: a) project's owners, b) engineering firms, c) construction contractors, d) union halls and their tradesmen, e) consultants & suppliers.

Project's owners operate under the paradigm of capitalism and their final objective is to always generate a profit. During mega projects, owners will exchange monetary value with hired stakeholders, against works completed in agreement with a written contract. In exchange, owners will expect from their stakeholders' optimal efficiencies at all time, stringent cost control from their construction management team as well as their subcontractors and will demand that projects are to be completed on budget and delivered on time.

Owner will indirectly deal with the union labour forces through the interpretation of their hired contractors. The owners' true leverage is economical only: without investment by owners, projects would not exist. During projects, owners will seek a) the lowest cost possible when completing projects, b) to be completed within the period allocated or before schedule, and c) will expect the highest work quality from all the stakeholders involved in a specific project.

Since owners provide the monetary value in exchange of works, projects' owners have the right to understand the root causes of why projects are running over budget and late in schedule deliveries. Table 1.1 summarizes the owner's objectives during a project, viewed by the researcher.

Table 1. 1
Project Owners' Objectives

Project Owners' Objectives			
Paradigm	Project Costs	Scheduled Delivery	Work Quality
Capitalism	Minimal	On-Time or Before	Highest

Dany Julien (2019)

The next stakeholder observed by the researcher are the engineering firms. These engineering firms will design the concept, and plan projects on behalf of owners during the phases of pre-feasibility (e.g.: front-end planning), feasibility (e.g.: detailed engineering) and complete the design during the construction phase (e.g.: execution). Engineering firms solely report to the projects' owners. Owners have a financial control over engineering firms and can demand design changes, however, there are financial cost to asking/making changes. Engineering firms are responsible of errors and omissions, as well as general liabilities. Although representing the owners' interests, thus achieving the lowest project costs possible, these engineering firms will also act as capitalistic entities and will seek maximum revenues during assigned projects. Hence during projects, engineering firms will seek to minimize project costs, while maximizing their revenues and profits. In the same time, engineering firms along with their construction partners, will attempt to complete projects on-time or before schedule, while expecting the highest quality from all sub-contractors and union halls involved in projects. Table 1.2 summarizes the engineering firms' objectives during a project, viewed by the researcher.

Table 1. 2
Engineering Firms' Objectives

Engineering Firms' Objectives			
Paradigm	Project Costs	Scheduled Delivery	Work Quality
Capitalism	Minimze costs / Maximize their revenues	On-Time or Before reputation at stakes	Highest

Dany Julien (2019)

The third group of stakeholders observed during this research were contractors. Season contractor will handle in their advantages, the power games between owners, union halls and their sub-contractors. During the execution phase of mega-projects, contractors understand that union halls have the instant capabilities to provide large quantities of manpower under short notices. Therefore, contractors' relations with their union halls are important ones and will be respected since their relationships are long-term based. On the other hand, the relationship between contractors and owners are often marked by unique contract between them and over a short period of time. Hence, unless there are long-term spending forecasted by owners in favor of a specific contractor, experienced contractors will tend to naturally protect their relationships with their union halls.

Overall, contractors' objectives will seek (1) to maximize revenues and profits, (2) attempt to complete projects on-time (lump sum contract) or later (time & materials), depending on the type of contracts, and (3) will expect to provide the highest quality of work from their management and union halls involved in projects. Table 1.3 summarizes the contractors' objectives during a project, viewed by the researcher.

Table 1. 3
Contractors' Objectives

Contractors' Objectives			
Paradigm	Project Costs	Scheduled Delivery	Work Quality
Capitalism	Minimze costs if Lump Sum Contract / Maximize costs if Time & Materials Contract	On-Time or Before reputation at stakes	Highest

Dany Julien (2019)

Union halls are the fourth stakeholders observed in this research. Union halls operate under the paradigm of protectionism and generalist. As protectionist organisations, union halls will protect their members before protecting owners and contractors, no matter how poorly the performance of a trade member can be at a construction site. Additionally, union halls do not welcome micro-management reporting on daily and even weekly basis. In fact, union halls rather have their performance activities reported as general as possible, therefore, union halls can be segmented as generalist organisations. Thus, union halls will see any attempt of gathering data collection, data mining or profiling, as an attempt to control their trade members, and subsequently giving project owners an upper hand on manpower. In the eye of union halls, this control of information through either micro-reporting or data collection is seen as the symbol of "*Big Brother Is Watching You*".

Hence, union halls will favor communications directly with contractors that have hired them rather than with projects' owners who seek control over the workers. During projects, union halls' objectives will seek (1) to maximize the amount of tradesmen / tradeswomen assigned to a specific project, (2) to maximise the amount of time to complete a specific project, thus any delays means more works for their members, (3) to maximize their revenues based on the maximum amount of workers that can be assigned to a project, and (4) to provide the highest quality from every trade member involved in a project. Table 1.4 summarizes the union's halls' objectives during a project, viewed by the researcher.

Table 1. 4
Union Halls' Objectives

Union Halls' Objectives			
Paradigm	Project Costs	Scheduled Delivery	Work Quality
Capitalism Generalist	Minimze costs - the more labours assigned to a project, the more contributions they received from their members	On-Time or Late deliver provide them with more workers and more contributions reputation at stakes	Highest

Dany Julien (2019)

The fifth stakeholders observed in this research were the consultants (and suppliers) which sale services, equipment and/or materials to project owners. Consultants and suppliers, although representing the owners' interest, will also act also as capitalistic organisations and seek maximum revenues during mega-projects.

Hence during a project, both consultants and suppliers will seek (1) to maximize their revenues and profits, (2) to supply their services or goods on-time or before installation, and (3) are expected to provide the highest quality for their services, equipment and materials. Table 1.5 summarizes Consultants' objectives during a project, viewed by the researcher.

Table 1. 5
Consultants' Objectives

Consultants' Objectives			
Paradigm	Project Costs	Scheduled Delivery	Work Quality
Capitalism	Minimal	On-Time or Before	Highest

Dany Julien (2019)

From the previous sections enumerated above, the researcher reviewed construction literatures and observed the following stakeholders' objectives during mega-projects, and are demonstrated in Table 1.6:

- All stakeholders will seek the highest quality of performance during a project. Simply said, their reputations are at stakes and having poor quality workmanship will be quickly known in the industry;

- The economy of the industrial countries is primarily based on capitalism, with some level of social democracy centred for the wellbeing (security, safety, and environment) of their employees. Hence, being capitalistic in nature, all stakeholders will seek to maximize their profits and revenues (capitalism). Meanwhile project owners will seek to minimize costs throughout every phases of the projects;

- Excluding the union halls, all other stakeholders will seek to complete the project on-time. Furthermore, contractors who work under a time & material contracts and union halls will benefit with late project deliveries.

Table 1. 6
Combined Stakeholder's Objectives

Combined Stakeholders' Objectives				
Stakeholders	Paradigm	Project Costs	Scheduled Delivery	Work Quality
Owners	Capitalism	Minimal	On-Time or Before	Highest
Engineering Firm	Capitalism	Minimze costs / Maximize their revenues	On-Time or Before reputation at stakes	Highest
Contractors	Capitalism	Minimize costs if Lump Sum Contract / Maximize costs if Time & Materials Contract	On-Time or Before Reputation at stakes	Highest
Union Halls	Capitalism Generalist	Minimze costs - the more labours assigned to a project, the more contributions they received from their members	On-Time or Late delivery provide them with more workers and more contributions reputation at stakes	Highest
Consultants	Capitalism	Minimize	On-Time or Before	Highest

Dany Julien (2019)

1.2.2. Construct no. 2: Fragmented Supply Chain Process

Surviving in today's dynamic global market requires a strong knowledge of its own internal and external supply chain processes. Thus, the philosophy toward achieving an end-to-end supply chain approach is applied throughout the manufacturing industries. So, what is supply chain? The concept of supply chain consists of a geographically dispersed network of stakeholders that supply and transform raw materials into distributed products (Gallear *et al*., 2013). Transparencies and integrated operations across all facets of business flows within and beyond the boundaries of a company are the keys to success in remaining in business today (Chan *et al*., 2014). In line with the previous statement, a transparent supply chain approach is also described by Christopher *et al*. (2004) and Delen *et al.* (2007) as:

- The degree to which a stakeholder pertaining to a supply chain network has the knowledge of the state of the goods or services it is being provided with from its suppliers' network;
- And accordingly, knowledge of the state of the goods or services it is supplying to its end-customers.

The second constructs that was observed by the researcher at the construction site of a mega-project was the following: The supply chain processes, understood as being transparent from end-to-end, is observed as fragmented, if not non-existent in the construction sector.

The researcher observed during mega-projects, that staffs amongst the construction and engineering management don't welcome the approach of an end-to-end supply chain philosophy. In fact, construction sites are most likely engineering-driven during the planning phases (front-end planning and detailed engineering) or construction-driven (execution phase). Therefore, this second construct simply states in other words that supply chain philosophy, as understood and practiced in many manufacturing industries, is not observed during mega-projects.

Various reasons stand in the way of achieving an end-to-end supply chain transparency during mega-projects. This doctoral thesis analyses various functionality of project management activities conducted by procurement, engineering, cost control and construction management. End-to-end supply chain processes in manufacturing requires a culture of trust, share knowledge and transparencies amongst all stakeholders. Many authors (Ala-Risku *et al*., 2006; Dainty *et al.,* 2001; Jang *et al*., 2009; Thunberg *et al.,* 2014; Young *et al*., 2011) cited adversarial culture, unwillingness to cooperate and general mutual mistrust amongst construction stakeholders during any mega-projects.

Creating material flow transparencies with the prime contractor and their sub-contractors prove to be a complex challenge for the researcher, while working as a Material Manager during a mega-project. Understanding the material flow of raw products to finish products and the labour associated with them, in manufacturing, is the key measurement to productivity. Regrettably, in construction, as observed by the researcher, measuring the flows of materials are not considered as essential activities. Hence, the time that materials are received at sites, how much time they will sit in a laydown or in a warehouse before installation, and by who, or what are their end-to-end final costs, are never recorded with such a manufacturing precision.

The supply chain life cycle never terminates in manufacturing. From planning, to sourcing, to making, to delivery, to returning/recycling, supply chain lifecycles are endless on both end of the spectrum process. However, in construction, once materials or equipment are received and verified during their arrivals at construction sites, the standardized supply chain processes terminate drastically. Key performance indicators (KPI) for supply chain processes such as sourcing, making, delivery, and returning, which are frequently used in manufacturing, are not usually measured in construction. In fact, construction sites are either engineering-driven or construction-driven. Where presidents in manufacturing industries are usually rooted from various span of works, such as accounting, operations, supply chain, legal affairs, and so on; the bosses of mega-projects are most likely issued from engineering and construction management staffs, leaving little chance to have someone running a project outside the box, such as with applying a supply chain approach.

Supported by literature (Ala-Risku *et al*., 2006), the researcher also noted several suppliers' failures, where suppliers, for instance, were unable to provide dates of arrivals of their materials at construction sites. Reasons for these supply failures were often due to the globalization distances and the transportation challenges associated with remote locations of mining projects. Other vendors had problems with fulfilling the accuracies of the purchases, with shortage of materials/equipment or back order deliveries. Finally, global procurement further challenges supply chain networks, especially at construction sites (Young *et al*., 2011), with customs issues or returning damaged equipment over long distance.

Therefore, the researcher believes that understanding and controlling an end-to-end supply chain process is essential during construction mega-projects. Unfortunately, the construction industry has yet implemented the benefit of integrating a transparent end-to-end supply chain approach, as one potential solution to control budget and scheduled delivery. Henceforth, the industry itself is guilty of not embracing the power of supply chain integration.

1.2.3. Construct no. 3: Status Quo in the Construction Industry

Poor productivity in construction and lack of understanding to understand why, as brought the necessity for a change in how construction projects are being managed (Ballard, 2010; Cheng *et al*., 2010; Dainty *et al*., 2001; Egan, 1998; Fernie *et al*., 2007; Latham, 1994). Owners, engineering & construction management teams, union halls and contractors make up the five major key stakeholders during mega-projects. Each of them has different objectives as described in section 1.2.1, roles and responsibilities. Despite a certain will to change during mega-projects, the construction industry, as observed by the researcher, has cultural and organisational challenges with their stakeholders. For instances, communicating together, unwillingness to share field data amongst themselves, or adversarial culture between union trades have made the industry stagnant. These status quo in the construction industry are also presented in various literatures (Ala-Risku *et al*., 2006; Dainty *et al.,* 2001; Jang *et al*., 2009; Thunberg *et al.,* 2014; Young *et al*., 2011).

Projects' costs overruns and late deliveries can also be attributed to the uniqueness of a project, which make them "one of a kind". Thus, trying to roll out any type of costly information systems (IS) with a standardized solution to a specific project is no easy task to convince today's construction culture. For most senior management in construction, the cost and risk of adopting new technologies outweighs the perceived benefits or a lack of guaranteed ROI by the owner. Hence, status quo in integrating information technologies at construction site remains the reality in today's industry.

Real-time reporting is still a myth, rather than a reality, for most mega-projects. That's largely because firms tend to use multiple software platforms that are manually monitored and disconnected amongst all sub-contractors. Coincidently, the researcher noted during a mega-project that two prime contractors had the same Enterprise Resource Planning system (*ERP*) as the project owner, however, none of the systems were plugged in as one IS platform. Instead, each contractor operated within their own silo and did not wish to share information, in the fear of losing tactical advantage from one to another.

Therefore, due to the uniqueness philosophy adopted in the construction industry, project managers have more often executed projects on building/reactive activities instead of proactive planning. Hence, this doctoral research observed a deep status quo philosophy being practice in the construction industry. In order to counter-fight this culture, it will require disruptive management and new innovative way of thinking and working during mega-projects.

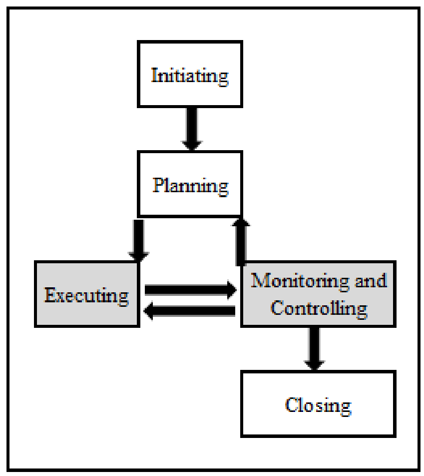
1.2.4. Construct no. 4: Homogeneity in Mega-Project Management

No matter what industries (oil & gas, mining, building & bridges) are under construction, project management is often performed in a similar manner. The researcher, while working at the engineering firm (2011-2014: participant observation) noted a similarities (homogenous) when planning, designing and constructing. These specialists systematically pursued the same process activities by most engineers, contractors and construction management teams.

Coincidently or not, mega-projects are run the same ways and tend to end up, too often, over budget and late in deliveries. There are many ways to describe the numerous phases and activities of construction project management. Essentially, projects go through a life cycle of phases which are typically: a) initiation, b) planning, c) executing, d) monitoring and controlling, and e) closing.

These five (5) common phases are illustrated in Figure 1.1. The construct of project management being homogeneous during the execution, stems from the reality that processes in manufacturing are for most part, supply-chain driven whereas project management are usually homogeneously driven by engineering and construction specialists during mega-projects.

Figure 1. 1
Project Life Cycle



PMBOK Guide and Standard (2018)

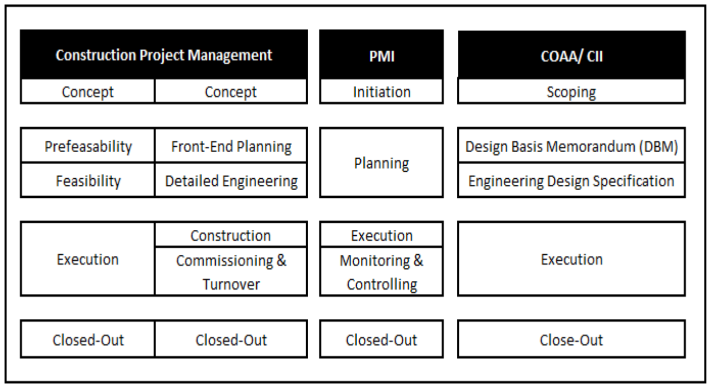
The researcher presents a breakdown of various phases of project management in Figure 1.2. For instance, the Project Management Institute, through their Project Management Body of Knowledge (PMBOK) uses five (5) project phases. PMBOK are illustrated in Appendix A. Two (2) of the most important construction organisations, which are the Construction Industry Institute (CII) / Construction Owner Association of Alberta (COAA) also utilised five (5) project phases. The project phase for the CII/COAA are detailed in Appendix B. For the purpose of this research, the phases of a construction mega-project are described by the following five (5) phases:

1. Conceptual;
2. Front-End Planning / Pre-feasibility;
3. Detailed Engineering / Feasibility;

4. Construction / Execution;

5. Commissioning & Closed-Out.

Figure 1. 2
Comparative Phases in Construction Project Management



Dany Julien (2019)

1.2.5. Construct no. 5: Macro-Reporting During Mega-Projects

According to several authors (Ballard, 2010; Cheng *et al*., 2010; Dainty *et al*., 2001; Egan, 1998; Fernie *et al*., 2007; Latham, 1994) poor productivity in construction and lack of understanding to why it is happening, as brought the necessity for a change in how construction projects are being managed. While working at the construction site (2014-2017), the researcher observed the following construct:

- Generally, contractors will rather tend to report their progresses in a macro-way, whereas manpower hours are grouped under one general area of works instead of breaking it down into several sub-areas, sub-categories or into sub-trades;

- Contractors don't have any incentive to break down hours of work in more finite way. For instance, contractors will prefer to report 30 pipe fitters, 12 hours/day in area, instead of having to describe each foreman's team and their daily progresses in terms of number of lines layout, number of valves installed or completed welds, to name a few activities. In other words, granular performance is not sought;

- Usually, the more details that are demanded by construction management teams (CMT) and owners, the higher the resistance from contractors and union halls in reporting them.

This construct is supported by Akinci *et al*. (2006) which states several problematic regarding reporting data during construction projects. For instance, the study states:

1. Missing and delaying information access constitute 50% to 80% of the problems in construction;

2. 30% to 50% of the field supervisory personnel's time is spent on manually recording field data;

3. Data are capture manually at site and are therefore dependent on people subjective judgements.

The construct of macro-reporting was also observed by the researcher. For instance, during one of the projects which the researcher took part (2014-2015), data reporting from the Prime Contractor no. 1 had been difficult, where the following were noticed:

1. Inconsistencies were often reported between planning and scheduling departments;

2. Daily activities were sometimes not aligned between contractors' management and their foremen/superintendents;

3. Inventory management was not seen as a core construction activities and lost materials were part of being in business. Prime contractors allowed themselves five (5) % discrepancies. Note that many manufacturers work with six sigma accuracies today;

4. Expediting materials prior to installation was not always promoted by contractors' management;

5. Foremen's timetables were poorly filled;

6. Crews' performance was hard to quantify daily, as contractors are pushing for weekly (macro) reporting.

While working at the mine's project, Prime Contractor no.2 (2016-2017) had a stronger management team and a work process in place before arriving to site. Its progress reports were more detailed, its inventory management was taken seriously and more accurate than Prime Contractor no. 1. Expediting preparation was also a strong part of its planning team. It is important to note Prime Contractors no.2 was contractually bonded with a lump sum contract versus a time & materials contract was in force Contractor no.1.

However, although the Prime Contractor no 2 seems to be better prepare at planning and executing that Prime Contractor no 1, both contractors pushed to report their respective progresses with a philosophy of macro-reporting. For instance, the daily and weekly reports for both contractors typically reported KPIs with the following categories: engineering, construction, health, safety and environment, cost control. The researcher noted that hardly any statistical or analytical analysis were ever performed on the general data obtained in the reports.

Contrary to the manufacturing industry, KPI obtained in construction are reported as is, with little effort to investigate them in deeper levels. In fact, the reporting culture in mega-projects seem to be the same universally with little innovation. Whereas in manufacturing, the basis of performance and productivity measurement are always directly linked to material and labour, in construction mega-projects, labour is the key KPIs and materials are just there to get simply installed. Obviously, poor productivity in construction and lack of understanding to why it happens, according to several authors (Ballard, 2010; Cheng *et al*., 2010; Dainty *et al*., 2001; Egan, 1998; Fernie *et al*., 2007; Latham, 1994) necessitate a change in how construction projects are being measured and analysed. Henceforth, the construction industry can learn from, for instance, the automobile sector, where micro-reporting, descriptive statistics and analytics prevails. From raw product to the end-customers, the automobile industry uses all tools available to understand the why's, the how's, then when and who's. Understanding that a mega-project is unique, it doesn't mean the construction industry can't borrow some of the general supply chain approaches, which the automobile industry has been so successful in using them. Hence, the construction industry is lagging in micro-reporting tools, and guilty of not embracing the power the supply chain.

1.2.6. Construct no. 6: Changes are Costly

It was noted that the phenomenon of changes during mega-projects are regarded as inevitable. Changes are generally seen as a major contributor to the managerial problems of being over budget and late deliveries in the construction industry (Lazarus *et al*., 2001). Changes are often associated with engineering flaws in planning, design and construction, as well as procurement issues in getting materials and equipment on time.

The dominant discourse in the construction industry is that changes are detrimental to a project and it would appear that negative connotations of changes go largely uncontested within the existing literature on the basis that project costs are privileged as an important factor contributing to project performance (Shipton *et al*., 2014).

As observed during this project, changes were always presented to the owner with additional costs based on additional labours and materials. Rarely the owners encounter cost reduction over a change requirement. For instance, the CMT requested during the projects several changes in the way the Prime Contractor no. 1 was managing its procurement, inventories and expediting activities. In response to the CMT's requests, Prime Contractor no.1's response was instantly evaluating the new cost activities at a minimum of one million dollar, without much consideration. At many other occasions when changes of works were requested, Prime Contractor no. 1 replied immediately by large sum of money based on their field experiences.

This approach by Prime Contractor no. 1 reflects Powell (2012) whereas changes in construction always cost money due to supplemental works (even though it will improve the process), the lost time from regular work standardized by the contractor itself, and the cost of change itself. Therefore, provoking changes will automatically cost money and has become a truism in the construction industry.

Part of the reasons why such rhetoric goes unchallenged and negative attitudes towards changes can incessantly propagate, are because project costs are privileged as the most important factor contributing to a project performance (Shipton *et al.,* 2014). Hence, based on this dominant discourse within the construction industry, changes are something to be minimized at the detriment to cost money. However, certain changes will save money, especially in integrating some, but not all, supply chain processes. For instance, change in managing inventories were implemented by the researcher in an action research methodology (ref: Chapter 3 – section 3.7.9 and Chapter 4 – section 4.2) with the Prime Contractors no. 1 and applied by Prime Contractor no. 2 with millions of dollars in savings (ref: Chapter 4 – section 4.2).

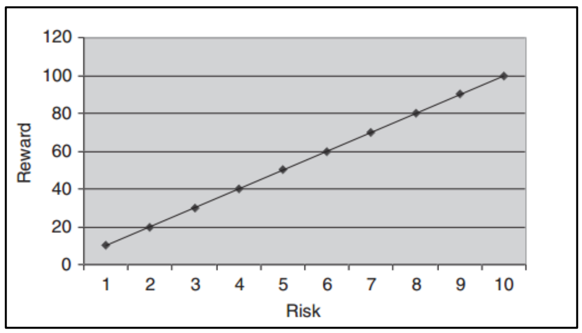
1.2.7. Construct no. 7: Uncertainty is Common

The final construct noted during the mega-project was uncertainty. The planning, control and improvement of the construction activities offer major challenges to any construction management teams. Going into a mega-project with known certitude of all events is simply impossible. In fact, in highly complex system such as mega-project, it is very difficult, if not impossible to identify all materials, labour and capital costs that are direct input to complex multistage processes to come (Gallear *et al*., 2013). Thus, uncertainty is a key factor influencing performance and an important unknown measurement for the operating environment.

According to Gallear *et al*. (2013), uncertainties have a major impact on the performance and managerial decisions, and the ability to align the construction stakeholders with the demands of the internal and external environment. The mega-project, which the researcher took part, was no exception to the rule of uncertainty in construction.

The notion of uncertainty in construction bring a level of risk during the execution of a project. Risk versus reward in the construction industry is counterintuitive due to the frequent uncertainties in the industry (Knight, 1965). In fact, risk acts differently in manufacturing and construction. The risk reward curve in the manufacturing industry is positively correlated as described in Figure 1.3, meaning that for each unit of risk, an approximate reward follows (Ceteris paribus).

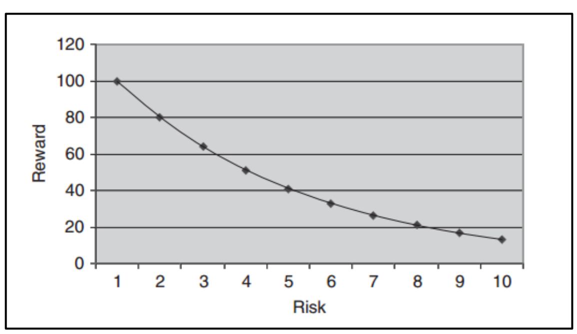
Figure 1. 3
Risk vs Reward – Manufacturing Industry



Knight (1965)

On the other hand, due to frequent uncertainties in mega-projects, the risk reward curve for the construction industry, according to Knight (1965), is negatively correlated (see Figure 1.4) where risks are always seemed as negative.

Figure 1. 4
Risk vs. Reward – Construction Industry



Knight, 1965

The level of uncertainty (risk) in supply chain can be associated in the literature by two theories: The Co-Alignment Theory and the Contingency Theory (Chandler *et al*., 2014). These two theories fit well in construction management and are better detailed in Chapter 2. The Co-Alignment Theory suggests that the ability of an organisation to adapt to the changing environmental contingencies to fit with the operating context is the key to survival and enhanced performance.

Similarly, the Contingency Theory suggests that managers play an active but limited role in the continuous process of adapting to the emerging contingencies (Grandori, 1984). The effectiveness of an adaptive response is dependent on aligning the response to the environmental context faced by the organisation (Strandholm *et al*., 2004). The focus of managerial decision-making is not primarily choice, but on gathering correct information about changes in the environment and examining the consequences of alternative responses because strategic choice among contingencies are more consequential (Astley *et al*., 1983). In other words, construction stakeholders will always face uncertainty (risk) during mega-projects, and managers as a team, will respond appropriately with the right fit at the right time are likely to achieve superior performance. The Contingency Theory is described in Chapter 2.

The motivation of this research stems from the recognition that uncertainty in construction mega-projects affect the efficiency, effectiveness and flexibility of the processes in place (Koutsoukis *et al*., 2000; Van der Vorst *et al*., 2002), but through the right fit and timing, uncertainty (risk) can be managed with success. Still today, the construction industry is plagued with challenges and is faced with projects being delivered late and over budget because:

- Construction sites are, for the most part, planned, designed or constructed homogenously, even though the sheer size and complexity of some of the mega-projects being built are so different from each other;

- The construction industry remains technologically stagnant in comparison with other industries. There is a lack of automated techniques to track components efficiently in the context of large mega-projects (Torrent *et al.*, 2009), and a lack of communication information systems sharing common knowledge amongst construction stakeholders;

- Union halls will protect their trade members' interests first. Delays will benefit them as employment will last longer and union halls will collect more fees from their work crews;

- Project owners will attempt to minimize cost and time, sometimes to the detriment of the end-product;

- Prime contractors must remain politically savvy in dealing with the union halls as they entertain a long-term relationship with them for other large projects;

- Attempt to track and locate construction resources (e.g. materials and labour) mean an increased controlled by management information systems, and reversibly viewed by contractors and union halls as a sort of Big Brother syndrome;

- Contractors prefer to control their materials and labour flows, as they can charge more during time & material (cost plus) contract;

- Construction contractors and sub-contractors along with management, work on different information technology (IT) platforms and will often be reluctant to convey information to each other, in a goal to position themselves ahead of one another (Jang *et al*., 2009);

- Even though materials accounts for 50% to 60% of the project cost (Ibn-Homaid *et al*., 2001; Kini, D, 1999; Torrent *et al*., 2009; Young *et al*., 2011), there is a lack of automated techniques to track components efficiently in the context of large mega-projects (Torrent *et al.*, 2009);

- Stakeholders are often characterised by the inclusion of large, medium and small sub-contractors and vendors, all working on different information technology (IT) platform, thus making transparent communication a cliché instead of reality;

- The supply chain processes with an end-to-end transparency approach, are unfortunately, for the construction industry, terminating at the arrival of materials, once they reach construction sites;

- It is hard to sell integrated IT system for a mega-project. According to several participants in the semi-structured interviews and survey. As construction specialists, they will implement an IT system if they can provide an immediate cost benefit (ROI) to the project's owner. On the other hand, if there is no immediate ROI, the IT system will most likely remain on the shelf for someone else to experiment with. Other participants in the interviews mentioned that project and construction managers are all about building, not proving solutions for a software integrator. In other words, they don't have time to experiment.

Therefore, the researcher believes that understanding and controlling an end-to-end supply chain process is essential during construction mega-projects. Unfortunately, the construction industry has yet implemented the benefit of integrating a transparent end-to-end supply chain approach, as one potential solution to control budget and scheduled delivery. Henceforth, the industry itself is guilty of not embracing the power of supply chain integration.

So, today, the construction industry remains one of the few industries not seeking the benefits of networking amongst themselves. Thus, the objectives of integrating an efficient supply chain strategies during mega-projects (Bolstorff *et al*., 2012) are in lined with most common business strategies, such as: a) to improve productivity and subsequently the performance factor, b) to reduce costs and to increase the profit margin, c) to deliver a project on-time, d) to deliver at the highest quality level possible.

1.3. RESEARCH QUESTION

The researcher understands they are various reasons causing the managerial problematics of cost overruns and late deliveries during construction mega-projects; and they are various potential solutions linked to the problematics. One solution is to investigate the integration of supply chain processes within the framework of an artifact.

This solution proposed in this thesis, is one of many potentials solutions that may help solving this managerial problematic (over budget and late deliveries) in construction project management. The activities of construction project management include procurement, engineering, construction, cost controls, worker management as well as project complexity (off and onsite).

In order to validate the value of this proposed artifact, the researcher put forward the following research question into two sections:

- While integrating a supply chain framework processes (end-to-end) in construction project management, which performance attributes and metrics are essential to a model having the objective of attenuating the managerial problems of cost overruns and late deliveries, while considering four (4) types of construction contracts?

- Subsequently, in this proposed supply chain-driven model, is there a certain dominance of performance attributes and metrics belonging more to engineering, procurement or construction activities?

1.4. RESEARCH OBJECTIVES

The primary objectives for the researcher are based upon the fact that most construction models reviewed in the literature don't present the following items:

- The implementation of a supply chain approach as the basic framework for the proposed model;

- By providing real-time measurement at construction site, which will help forecasting projects' costs and delivery scheduled throughout the construction phases;

- By offering a construction model that is friendly to use by construction stakeholders; and provide performance attributes and metrics, which are useful to construction specialists;

- By providing performance attributes and KPI metrics, which are useful to the industry, in terms of engineering (E), procurement (P) and construction management (CM) activities;

- By offering a model that covers all phases and aspects of construction mega-projects, beginning with conceptual, front-end planning, detailed-engineering and ending by the construction;

- The model must adapt to several types of construction contracts, such as time & materials (cost plus) and lump sum contracts.

Therefore, this research will focus its objectives, along with the Design-Science Research (DSR) approach, (a) by designing an artifact (Construction Performance & Productivity Model - CPPM) that covers the essential activities of procurement, engineering, construction, cost control, employee management and project complexities during mega-projects; and (b) by supporting the DSR with various temporary kernel theories related to construction management.

SECOND CHAPTER
THEORTICAL CONTEXT

2.1. CONSTRUCTION INDUSTRY

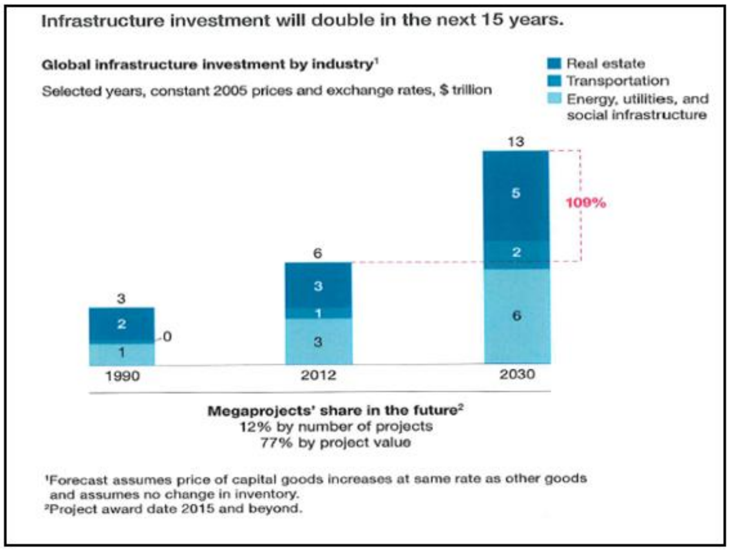
Today, the Canadian construction industry which operates in a changing dynamic environment, is facing an increased global competition. As trade barriers fall across the industrial countries or become obsolete; and transaction costs decline between countries; new global competitors located in Europe or South East Asia, are now bidding into previously more protected domestic markets that used to belong to the Canadian construction companies only. Today, Canadian companies can't no longer expect to be protected by their government due to trade agreements. Fortunately, new global markets have also opened for these same construction companies. Evidently, this negative pressure cause by trade borders opening to foreign competitions, can be funneled into a positive one, and encourage construction companies to build new efficient ways of constructing, in order to compete into these global markets, not just pan-Canada. Hence, this doctoral thesis believes, that construction companies with superior engineering, procurement and construction processes, along with cost controls and optimum labour productivity, and supported by a supply chain approach, will improve their sustainable competitive advantages on global levels.

2.1.1. Construction Economy

Construction activities have a great economic significance, producing 6% to 10% of Gross Domestic Product (GDP) amongst industrial economies (Gann, 1994). Additionally, Gann (1994) expressed that the construction sector, within its overall economy, produced up to 50% of Gross Fixed Capital Formation, including building, factories and infrastructure, which are essential for other economic and social activities such as automotive, pharmaceutical and chemical industries.

Construction investments are also growing fast, whereas in 2013, Changali *et al*. (2015) stated that global investment in sectors such as energy, infrastructure, mining and real estate were $6 trillion (USD). It is also forecasted by the same authors that in 2030, the global investment could reach $30 trillion (USD). Figure 2.1 displays the global investment in infrastructure related to construction from 1990 to the year 2030.

Figure 2. 1
Global Infrastructure Investment



Mckinsey & Co. (2015)

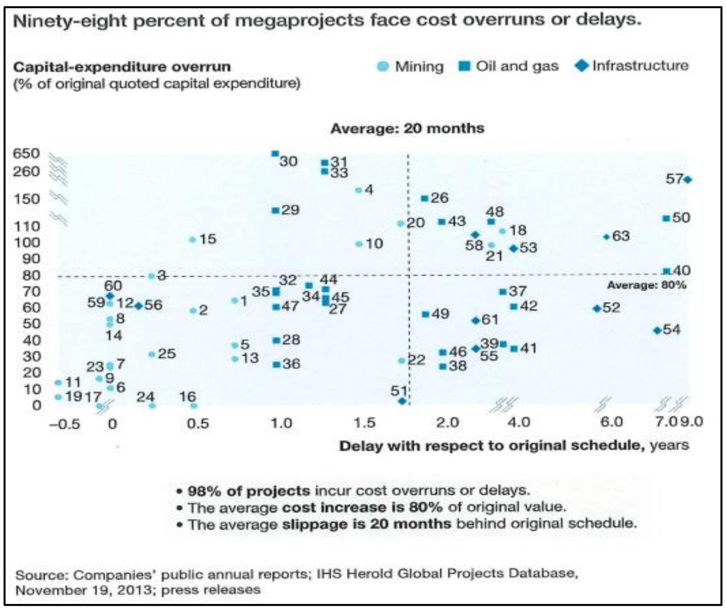
In the past, the Canadian construction industry has enjoyed a protective market and were isolated from outside threats. Today, as trade barriers are removed with new economical agreements, Canadian construction companies will have to deal with an increased global competition. In fact, major mega-projects in Canada are now often bided with or against foreign joint ventures. Some example of global bidders within the Canadian markets are:

- The Muskrat Falls Hydro Project in Newfoundland which awarded to Astaldi, an Italian company;
- The BC Hydro Site C Power Dam was awarded to a multi-nation joint venture under Aecon, Dragados, Flatiron and EBC Construction;

- The Montreal NouvLR-Metropolitain Express Network was also awarded to a multi-nation joint venture under SNC Lavalin, Aecon, Dragados and Pomerleau/EBC.

Unfortunately, the systematic managerial problems of running mega-projects over budget and delivering them late are widespread globally in the construction industry. According to Changali *et al. (2015)* of McKinsey & Co., 98% of mega-projects suffers cost overruns of more than 77% above the initial budget. Moreover, 98% of these same mega-projects were at least 40% late in deliveries. Figure 2.2 illustrates costs and schedule overruns on the global construction industry.

Figure 2. 2
Costs & Schedule Overruns



Mckinsey & Co. (2015)

2.1.2. Construction Productivity

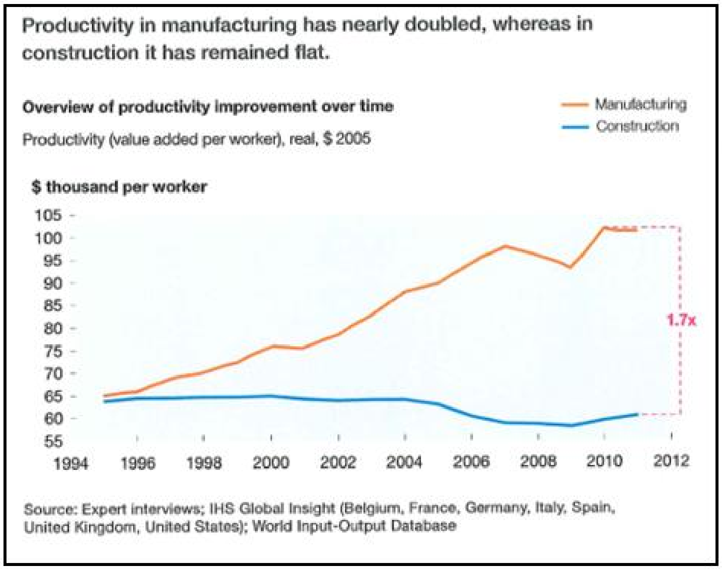
Poor productivity in construction and the lack of understanding why it happens, as brought the necessity for a change in how construction projects are being managed (Ballard, 2010; Cheng *et al*., 2010; Dainty *et al.,* 2001; Egan, 1998; Fernie *et al*., 2007; Latham, 1994). One of the most valuable abilities of project and construction managers is to forecast accurately. Information technologies could give construction companies greater insight into understanding costs, schedule, quality, and safety performance. These information systems would allow them to accurately forecast the amount of resources required when the project scope changes, ensuring that materials and labour are budgeted and scheduled efficiently.

Despite the will to change, the construction industry still displays weaknesses when comes the decision to (a) integrate information technologies, (b) implement a supply chain approaches, (c) deal with unavailable data for construction managers, (d) manage the unwillingness to cooperate between stakeholders which are often adversarial cultures. Therefore, the holistic belief in which, a project is seen as unique, makes it hard to implement management information systems and duplicate success from sites to sites (Dainty *et al.,* 2001; Thunberg *et al.,* 2014).

Cost overruns and late deliveries in construction mega-projects are not the only reasons for the poor level of productivity in that industry. Despite an increased capital-labour ratio and higher levels of educational attainment in the construction workforce, the labour productivity in Canada, the United States and the UK have been lower for the past fifty (50) years.

In fact, over a thirty-nine (39) year-period [1961-2000], the US construction sector experienced less than one half the average annual rate of increase in output per hour compared to the business sectors (+0.8% versus +2.0%). By contrast to the United States, the productivity level amongst European manufacturers have nearly doubled the productivity performance compare to their counterpart in construction. These results are demonstrated in Figure 2.3 (Agarwal *et al*., 2016).

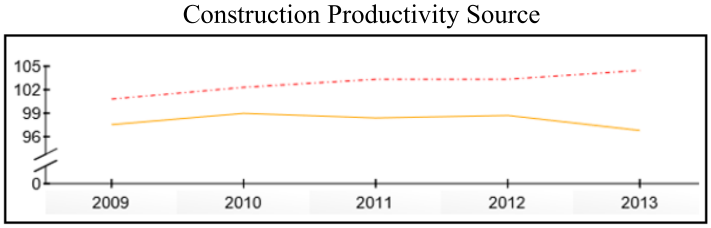
Figure 2. 3
Productivity in the European Sectors



Mckinsey & Co. (2015)

Other examples of global productivity issues in construction are demonstrated by Statistics Canada. Published between 2009 and 2013, its productivity performance decreased -0.2% per year on average. In comparison, labour productivity for the Canadian economy increased 0.9% per year. Additionally, in the most recent year, labour productivity in the Construction sector decreased -1.9%, compared to an increase of 1.1% for the Canadian economy. Figure 2.4 illustrates changes in labour productivity for the construction sector in comparison to the Canadian economy between 2009 and 2013.

Figure 2. 4
Construction Productivity Source



Statistics Canada (2017)

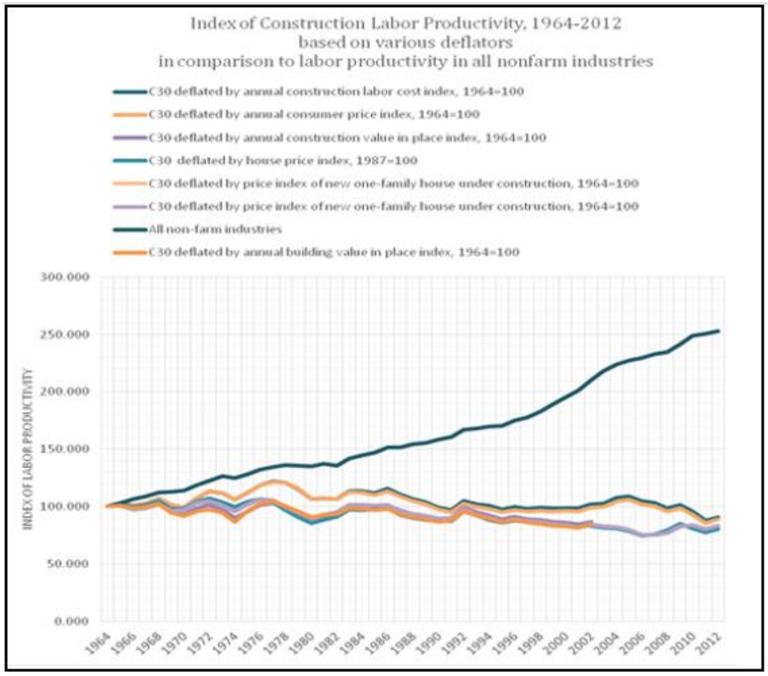
Chae *et al*., (2010) demonstrated similar issues with construction productivity in Germany and the United Kingdom. Similarly, to Canadian and American's construction industries, the Germans and the UK construction industries had not kept pace with the overall manufacturing industries in Europe. Figure 2.5 illustrates that Germany and the United Kingdom's construction productivity against the total economy of Europe.

Figure 2. 5
Germany & UK Construction Productivity

Mckinsey & Co. (2015)

Similarly, to McKinsey *et al*., (2010) and Statistic Canada, the US Census Bureau indicates that labour productivity for the construction industry slightly decline over the last fifty (50) years with a linear trend of -0.32% per year, while the trend for all non-farm industries demonstrated a positive trend of 3.06% per year. The net impact (negative over positive trend) over the last fifty (50) years is very significant (Teicholz, 2013) for the US economy. Figure 2.6 illustrates the negative productivity in the United States of America.

Figure 2. 6
Construction Labour Productivity, 1964-2012

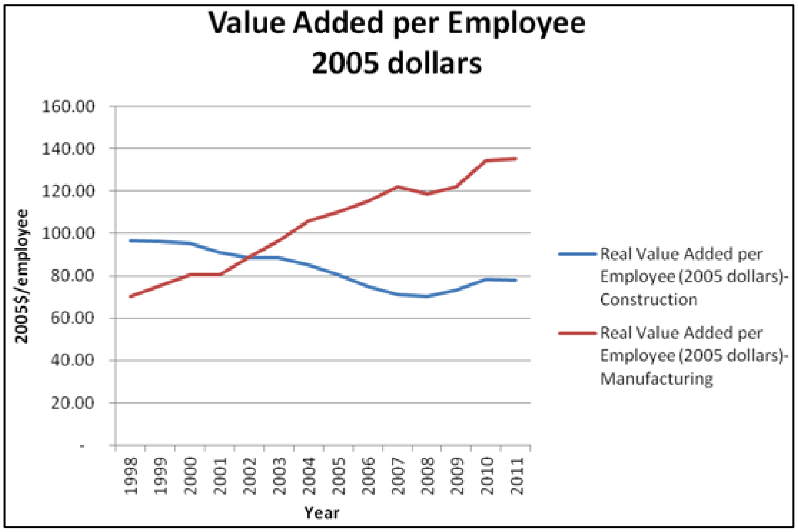


Teicholz (2013)

The US Census Bureau also employs another way when measuring its labor productivity by calculating it with the Value Added (VA) Method per employee. This method reflects the net value added within the industry it pertained to. However, the overall results are the same: weaker productivity in the construction industry when compared to the manufacturing sector.

The Value Added per employee in the construction industry has also declined over a similar period, reflecting less output per employee and lower productivity in construction. On the other hand, the Real Value Added per employee in manufacturing have increased during the same period, reflecting more output per employee and higher productivity in manufacturing. Figure 2.7 illustrates the Value-Added Method per employee.

Figure 2. 7
Value-Added Method for Construction & Manufacturing 1998-2011



Teicholz (2013)

Technological journals, periodicals, textbooks, etc., all agree in the statement of an existing systemic performance and productivity problems in the construction industry. The construction sector, as stated in this chapter, is said to lag behind the business sector as a whole and in particular, the manufacturing sector. According to Teicholz (2013) and Agarwal *et al.*, (2016), the causes of these 'systemic problems' in construction are variously attributed to:

1. Poor organisation attributed to performance management. Unresolved issues stack up because of lack of good communication amongst construction stakeholders, transparencies and lack of accountability amongst themselves;

2. A decline in the ratio of skilled-to-unskilled labour and stagnation in labour quality;

3. Stagnation in labour quality compared to improved labour quality in the economy, where 'labour quality' is proxy by educational attainment;

4. Lower capital/labour ratios arising from the craft nature of many construction process;

5. Lower adoption of IT which has been a low productivity driver in other industries.

Poor performance and productivity in construction and the lack of understanding to why, has forced the necessity for a change in how construction projects are being managed today (Agarwal *et al*., 2016; Ballard, 2010; Cheng *et al*., 2010; Dainty *et al.,* 2001; Egan, 1998; Fernie *et al*., 2007; Latham, 1994; Teicholz, 2013). Observations from these authors enumerated herein this paragraph, coincide with the researcher' observations during the study period. The root cause of overrun cost and late deliveries amongst mega-projects can be put at fault in part to:

- Stakeholders are accepting the status quo in the construction industry, because mega-projects by themselves are understood to be too complex and unique in their endeavours;

- Stakeholders agree that it is near impossible to pinpoint all variables that would control a project under budget and timely schedule, hence project managers will often manage in reactive ways, instead of a proactive manner;

- The construction industry is not yet confident in adopting an end-to-end supply chain approach across its various project phases, due to the domination in nature of engineering-driven and construction-driven cultures;

- Construction stakeholders are faced with an industry steadily using the same KPIs, and the same report formats from project to project, when so many other variables could be used through analytics;

- Unmistakeably, the construction industry is criticized for delivering projects late and over budget due to the failure in effectively tracking and locating the two most important variable in supply chain: materials versus labours.

2.2. MANAGEMENT INFORMATION SYSTEMS IN CONSTRUCTION

The nature of the construction industry has been highly reactive rather than proactive when dealing with projects' cost overruns and late deliveries. The tendency has been to try to accomplish design and construction at almost any cost, so to achieve project on time (Silver, 1988). Unfortunately, neither budget not delivery is met in most cases.

With today's IT solutions and mobile applications available on the market, data and analytics, engineering, procurement and construction management can provide real-time insights into their mega-projects. By adopting more IT solutions, key stakeholders in construction could make more informed decisions in the field, enabling swift action to resolve problems as soon as they start, or even before they start.

The researcher understands that mega-projects processes are created for a unique project and disbanded after the project is completed (Dainty *et al*., 2001). Hence, the uniqueness of a project combined with its short-term duration, accompanied with large number of stakeholders, all having similar or different objectives, do not favor large capital (CAPEX) investment in information technology (IT).

Construction stakeholders are often characterised by the inclusion of large, medium and small sub-contractors and suppliers, all of them having different types of information technology (IT) platforms. Some are executing works for a small period, whereas others are assigned large contracts that will last several years. The characteristics of several stakeholders working within the same construction job site, bring a challenge to any type of communication and integration. The reality in construction is that owners and stakeholders are reluctant to convey transparent information between each other, atypical of an integrated supply chain approach that is employed in manufacturing. It is, in fact, the nature for each stakeholder in construction to position itself, ahead of others (Jang *et al*., 2009). Therefore, due to so much differentiation in IT requirement, construction stakeholders will often experience inadequate communication all along mega-projects.

Weak communication standards in construction often produce inconsistencies in reporting and subsequently stakeholders don’t have a common understanding of how project is faring at any given time. Subsequently and consequently, the difficulty to have stakeholders’ transparencies at job sites is a reality of today’s construction mega-projects on a global scale.

Understandably, unless project owners have large PMO (Project Management Office) and the same infrastructure (i.e. stick built) are being repeated at later time over various sites, investing in a commune IT platform for several stakeholders to share, will most likely not happen as an investment for one project alone.

Hence, a reason that was observed by the researcher for not adopting an IT platform during a mega-project was often based on assessing a ROI as a construction software investment, when in fact, it should rather be considered as a business improvement investment. Thus, considering the IT platform as a business improvement investment, the software itself, needs to be viewed as an enabler of business processes that delivers strategic value, not just an IT purchase like tablets and smartphones. Supporting the researcher's observations, Carr (2003) further argued that the biggest technological error made during construction, is focusing on a technology as an end in itself, rather than a means to strategically potent ends.

In order to have a measurable ROI, a construction company needs to baseline its current processes (locating your inefficiencies and areas for improvement) so that you have a metric to measure against. However, a vast majority of construction companies manage their projects with a cumbersome combination of email threads, Excel, and non-integrated project software, creating a baseline to measure against is impossible. By the time the data are collected, they are most likely out of date and project managers can't see the real picture, not to mention the amount of colossal work by staffs to report on the data in a meaningful way. However, having an integrated IT system in place, would do all the heavy lifting of aggregating data for every construction activity and could present them in easily digestible dashboards and reports.

Although not a common practice in construction, it is crucial to house all the project information and processes within either a single software platform (e.g. Project Wise), or a suite of solutions that are connected through an integrated construction platform. The primary objective to house the project information into one software solution is to eliminate data silos and double entry. Other objectives for IT integration are the many savings in rework, project delay, litigation.

Mega-projects around the world are becoming bigger, bolder and more complex, and with complexity comes risk. Information technologies such as remote monitoring, Internet of Things, RFID, automation allowing intelligent driver, data analytics and tablet visualization have enormous potential to speed up project progress and improve accuracy. However, the construction industry is still rated as being in an infantile phase, when comes to information technology.

As noted in the previous chapter, the construction industry has traditionally been viewed as technologically stagnant in comparison to other industries (Young *et al*., 2011; Zai *et al*., 2009); whereas field productivity has been flat for decades. There is also evidence where the construction industry is generally considered slow to adopt new management techniques and technologies (Khalfan *et al.,* 2006). According to KPMG's article entitled - Building a Technology Advantage: Global Construction Survey 2016; when it comes to technology innovation, just 8% of the construction companies fall into the cutting-edge visionary category, while 69% of them are considered either followers or behind the curve.

Information technologies (IT) required considerable investment and effort to be successfully applied in real construction projects (Chae *et al*., 2010). IT can assist construction organisations in many ways. Information technologies use in supply chain activities focus on improving the efficiency, accuracy, and the security of materials and information flows, whether across a supply chain network spread globally or within an organisation's internal operations (Canon *et a*l., 2008). In fact, literature demonstrates supply chain technologies can facilitate traceability, providing real-time tracking, and improve collaboration across an organisation (Canon *et al*., 2008) or a project.

Supply chain technologies include, but not limited to, any Auto-ID tracking technologies, which can assist management to take real-time decision. For the purpose of this thesis, the researcher reviewed the following technologies:

- Radio-Frequency Identification (RFID) with Geographical Positioning System (GPS);
- Real-Time Location System (RTLS) with Geographical Positioning System (GPS);
- Warehouse Management System (WMS);
- Transportation Management System (TMS) / Intelligence Transportation System (ITS).

2.2.1. RFID

So far, the use of RFID tracking technology in construction projects is most likely the most popular one, especially in the Oil & Gas industry where lots of piping and stick building are constructed. RFID involves the use of tags, transponders and a reader that can collect data and manage it and retrieve it at a later time (Akinci *et al*., 2006; Behzadan *et al*., 2008). RFID technologies in construction can be applied with engineering and design, material management, fleet/tool/equipment maintenance and field operations (Jaselskis *et al*., 2003).

RFID can be used beyond its tracking functionality. Chin *et al*. (2005) propose the integration of RFID and 3D-CAD model systems at construction sites to support scheduling, sequencing and planning. Along with CAD models, RFID tagging could also automate the data collection process for the progress management including the hours that are earned and burned during a project.

However, the high cost of RFID readers and transmitters influence the decision to adopt this tracking technology, even though the implementation cost equals that of the embedded tracking system (Jang *et al*., 2009). However, the direct comparison of implementation costs cannot represent the actual project situation, because the condition during the construction execution will vary from project to project. Hence, the fact that cost evaluation is related to each project, will cause a challenge to quantify the cost savings and expected benefits. In summary, RFID technology can be easily integrated to a supply chain platform which will improve mega-projects' processes, but proving a ROI remains a reality in mega-projects.

2.2.2. RTLS

Real-Time Locating Systems (RTLS) technology is usually some form of radio frequency (RF) communication, infrared-optical or acoustic-ultrasound. Wireless RTLS tags are then attached to objects or worn by people, and in most case, a fixed reference points receive wireless signals (passive or active) from RTLS tags in order to determine the location.

RTLS are used to identify and track the location of objects or people in real time, usually within a building or other contained area such as a mine shaft, inside a ship hull, or any type of tunnels for hydro, mine and road projects. Thus, RTLS technologies and systems are frequently used for tracking moving assets and staff located in underground areas.

When linked to internal work processes, such as a loader's bucket working inside a tunnel, the RFID/RTLS technologies can provide automated ubiquitous monitoring of mobile activities inside and outside the tunnel, enabling unprecedented control for greater efficiency and real-time decision making (Curtin *et al.*; 2007). The integration of work processes and geographical tracking system such as RFID/RTLS is mentioned in Lee's work (2004). The author calls for integration, efficiency and mobility, which will subsequently offers improve Triple A - agility, adaptability and alignment. In summary, RTLS technology can be easily integrated in construction, which can improve mega-projects' processes.

2.2.3. WMS

WMS technologies aim to control the movement and storage of materials within a laydown, warehousing or a staging area, while processing the associated transactions, including shipping, receiving, put away or picking. The WMS systems can also direct and optimize stock based on real-time information about the status of installation.

Surprisingly enough, most construction projects do not use a warehouse system management system (WMS) during the construction phase, even though millions of dollars of equipment and materials are procured throughout the life cycle of a project. Instead, construction stakeholders will tend to rely simply on Excel spreadsheet or some sort of Enterprise Resource Planning (ERP) that is not project driven.

ERP, such as SAP or Oracle, are basically a multi-departmental enterprise system. Unfortunately, these powerful ERP systems like Oracle or SAP, as observed and practiced by the researcher, are not suitable for project management, especially during construction. In fact, it is well understood amongst logistics professionals which specialised in construction project management that most ERP systems like SAP or Oracle do not perform well on the same level as would a simple WMS. In summary, WMS technology can be easily integrated to a supply chain platform which will improve mega-projects' processes.

2.2.4. TMS

TMS is a subset of a WMS platform and is concerned with transportation operations. In general, TMS will offer the user various suggested routing solutions. These solutions are evaluated and once the best provider is selected, the solution typically generates electronic load tendering and track/trace to execute the optimized shipment with the selected carrier.

Intelligent TMS are used in OPEX, where un-manned hauling vehicles used to haul minerals from point A to point B. However, during CAPEX, the researcher, in its many years of working in project management, did not come across one project that use a TMS software. The reason is that most traffic is a one-time only pattern and experience freight forwarders can assist in optimizing the best route. In summary, TMS technology can be easily integrated to a supply chain platform, however, this technology is not necessary for the success of a completing a project on schedule and budget.

2.2.5. Data management

Traditionally, managers and supervisors have been able to control most aspects of the construction operations. Today, big data and real time transmission of data pose challenges in the ability for managers to process all the data information in a timely manner (Angeles, 2005).

From the time feasibilities studies were engaged three to five years prior to the execution of construction, large amount of data (big data) have been created by the engineering firms. These data are eventually dumped, in large quantity and at a fast pace, to most construction stakeholders, right at the beginning of the construction phase. Big data dumping is therefore a problem for achieving end-to-end supply chain transparency during the construction phase. In order to take full advantage of these data, their collection during the construction phase must be accurate, timely and comprehensive.

Today, construction stakeholders must be able to have the appropriate capabilities to analyze and interpret voluminous data being transfer at fast speeds (Angeles, 2005). Data management has become a challenge, to construction managers and contractors, which they can't humanely analyses without proper management information systems. Hence, a major concern with data management is related to the effective analysis and use of large amount of data generated, captured by an effective supply chain network (Li *et al*, 2006; Ngai, *et al*., 2009; Srivastava, 2004).

Overall, decisions are only as good as the information that they are based on, and information is only as good as the data it is composed of. Following the large amount of data being transferred from the detailed engineering to the construction phase, project owners, contractors and other construction stakeholders must have a strong understanding of their own operational processes, and determine the volume of information exchange that are valuable to them (i.e.: garbage in, garbage out).

Thus, thresholds or triggers for passing on data from one application (engineering) to another (construction) will have to also to be set up (*RFID* Journal, 22 Sept 2003) early in the detailed engineering phase. Failing to control these data flows (materials, equipment, labour, cost and time) before construction start, will promote miscommunication and lead projects to be completed over budget and delivered late.

Therefore, receiving big data is now reality at the beginning of any construction project. Prompt updates of field information regarding material status, locations, quantity, installation updates, etc. will make it easier to manage and better control the overall construction processes, especially when optimizing cost and time delivery. In essence, control of data management is an essential activity to mega-projects.

Further problematic happens after receiving the tsunami of information, whereas sharing them amongst stakeholders is not a simple task of just doing a transfer of data. Some of the information maybe confidential to certain stakeholders and can't be shared amongst some of them taking part in the same project. Thus, construction management teams don't always have the luxury of operating an independent ERP system like management in manufacturing plants, which suppliers and customers are linked together. Ironically, the researcher witnessed two large companies using a common ERP (e.g.: SAP®) at the same construction site. But either one was able to transfer or exchange information, fear of the Big Brother paranoia or getting data infections.

2.2.6. Data Warehousing

The amount of data received, as observed by the researcher during the years working at corporate and field assignments, could be easily qualified as big data. However, what was more astonishing during that period of research, was the lack of trying to deciphering them into analytics. Manufacturers have understood for many years that in order to operate an accurate supply chain network, data collection and data warehousing must be accurate, timely and comprehensive. The researcher also believes the same data accuracy is as important in construction, as it is in manufacturing. However, engineering firms and construction companies which are commonly taking part in building mega-projects works in silo communication and don't collect data as one entity, nor they carry any sort of analytics. Although the lack of data warehousing and data analysis in construction, it is vital for obtaining correct assessment of job conditions that are used in decisional management.

2.2.7. Security & Privacy

There are several privacy issues to consider when using information technologies such as RFID, GPS and other tracking devices (Srivastava, 2004), especially with tracking individuals for non-safety reasons. Technologies like GPS/GIS stored in vehicle can be located, anywhere and anytime, without the consent of the individual/driver. Thus, tracking a vehicle at a construction site may cause some type of privacy concerned against some individuals, if viewed by them as Big Brother is watching you!

Other examples of security issues when implementing information technologies are profiling workers while measuring work performance against personal information such as age, gender, what province they are living in, which union halls they belong to, etc. Other privacy issues are also stated by Ngai *et al*. (2009), with eavesdropping, denial of service, unauthorised tracking, fraudulent tags, readers' attacks tempering (spoofing) and inventory jamming are some of the concerns with supply chain's information technologies. According to Krotov *et al*. (2008), privacy and civil liberties can be threatened by information technologies because these geo-tracking technologies bring:

- Hidden placement of tags;
- Unique identifiers for all objects worldwide;

- Massive data aggregation;
- Hidden readers;
- Individual tracking and profiling;
- Communication.

In summary, having an integrated IT platform would eliminate repetitive processes and greatly reduce the need to manually enter information while streamlining and/or automating operations across departments. Owners, senior management, contractors and other stakeholders also demand accurate and transparent project information in order to make informed decisions. For instance:

- With an integrated IT platform, all data are housed in a single location, providing better access to more reliable data for all construction stakeholders;
- With an integrated IT platform, the costs of hardware, replacements, repair, upgrades, personnel, manual backups, and ongoing training are also greatly reduced;
- The ability to instantly access the most up-to-date data is vital to confirm the reliability of project reports, and proactively address potential issues while there's still time;
- An integrated IT platform offer efficiencies with greater productivity in the following: a) reduced level of inventory through improved planning and control; improved production efficiency which minimizes shortages and delays, b) reduced rework due to better scheduling and interactive drawings with all pertinent information readily available, c) faster RFI and change order turnaround time with the help of team visibility, automatic reminders, and overdue notifications, and d) automation in construction.

The construction industry is viewed as technologically stagnant in comparison to other industries (Young *et al*., 2011; Zai *et al*., 2009) and is generally considered slow in adopting new management information systems (Agarwal *et al*., 2016; Khalfan *et al.,* 2006; Changali et al., 2015; Young *et al*., 2011; Zai *et al*., 2009).

Even though materials accounts between 50% and 60% of any projects' CAPEX (Ibn-Homaid *et al*., 2001; Kini, D, 1999; Torrent *et al*., 2009; Young *et al*., 2011), there is an evident lack of automated techniques to track components efficiently in the context of large mega projects (Torrent *et al*., 2009). Such lack of automation and tracking software platform result in labour overtime, expediting costs and tracking inefficiencies at construction sites. The lack of management information system result in projects being completed over budget and late in deliveries, which were not reflected in the original projects' costs and schedules (Smith-Daniels *et al*., 1984).

For the most part, construction projects still depend on human skills and inputs. Unfortunately, these materials/equipment input make tracking processes labor intensive, infrequent and prone to errors. Such errors are reported in Chapter 4 - Results. Complementing these error-prone manual reporting are the harsh site conditions such as extreme cold, rain, mud or dust can greatly increase the challenge of identifying components (Torrent *et al*., 2009). It is truer when materials/equipment are located at laydowns and exposed to the outdoor environment.

Furthermore, inefficiencies related to manual reporting, recording and transferring field data into actual tracking systems, become even more important as the size and scale of construction projects increase (Jang *et al*., 2009; Thomas *et a*l., 2005, Young *et a*l., 2011). Thus, controlling the various level of ambiguities (errors and accuracies) during the construction phase are critical in order to complete projects on budget and on time.

Automating construction sites appear to be a solution to improve the overall performance and productivity of a project. In fact, there are numerous studies that have stated improved accuracy and timeless of data when automation was introduced to support various project activities at construction sites (Akinsi *et al*., 2006, Chae *et al*., 2010; Ergen *et al*., 2011). For instance, Jang *et al*. (2009) stated by deploying RFID at a construction site saved up to 64% of the labor cost associated with the material tracking. Other studies found that automation to produce 10% to 12% savings in labour costs (Ibn-Homaid *et al*., 2001, Bell *et al*., 1987, Zhai *et al*., 2009).

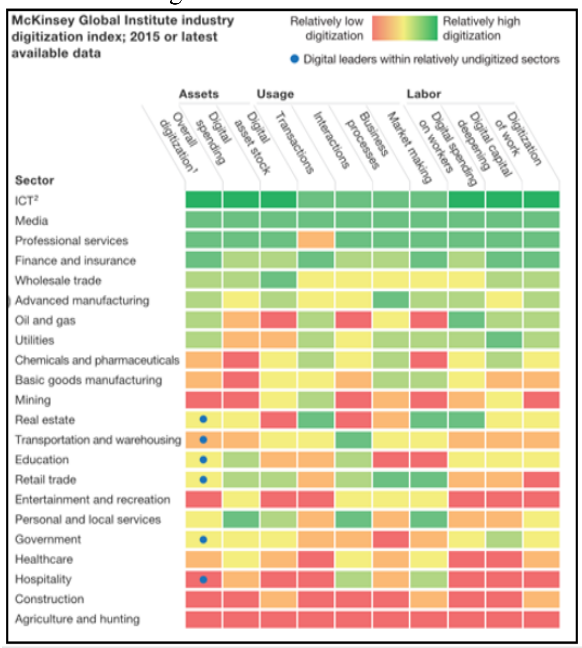
Young *et al*. (2011) concluded that automated tracking systems have the potential to increase visibility and reduce uncertainty within a construction supply chain network. For instance, Akinci *et al*. (2006) reported when automation was integrated at a construction site, there was a 50% to 67% reduction in non-valued added activities. Sardroud *et al*., (2009) stated that automated systems in construction projects will have to meet five (5) element of project management in order to be successfully implemented and face the ROI elements: a) scope, b) quality, c) safety, d) cost and e) time.

Zhai *et al*. (2009) also assessed both automation and integration in the construction industry. The authors found out while both integration and automation are correlated with better productivity performance, the analysis suggested that integration had a greater impact than automation (Zhai *et al*., 2009). Thus, it can be said that automation is a prerequisite to integration, however, integration is an enhancement of automation (Zhai *et al*., 2009).

Agarwal *et al*., (2016) of McKinsey & Co. state less than 1% respectively of their companies' revenues is spent on research and development (R&D) and/or information technologies (IT). This lack of R&D, automation and integration correlate with the construction culture of uniqueness and the related difficulty in investing in IT.

Because of this uniqueness in project scope, the construction industry has focused, therefore, on making small incremental improvements over the years. Obviously, there is a deep cultural symptom that make IT integration slow to be adopted in construction. Overall, the researcher believes that it would most likely be beneficial to the construction industry to manage construction sites with more integrated IT systems. In the future, as the construction industry changes, future construction sites will become hopefully, more intelligent and integrated, as materials, components, tools, equipment and labors become elements of a fully sensed and monitored environment (Wood *et al*., 2005 in Zhai *et al*., 2009). Figure 2.8 illustrates the level of digitization in the construction industry, which is evidently low.

Figure 2. 8
Digitization in Construction



Mckinsey & Co. (2016)

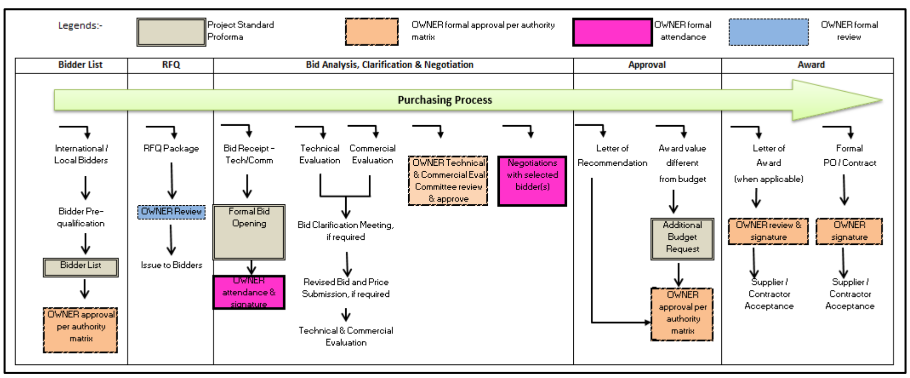
2.3. CONSTRUCTION vs. MANUFACTURING

When comparing the conceptual and operational processes in construction and manufacturing, these two industries reveal both similarities and differences. Both construction and manufacturing industries use in their own ways, materials and labors for measuring productivity factors. As stated in the previous chapter, the importance of receiving materials accurately and on time, along with understanding its own labours' productivities performed, are two very important variables when considering the success of a project and the effectiveness of a manufacturer.

2.3.1. Similarities between Construction and Manufacturing

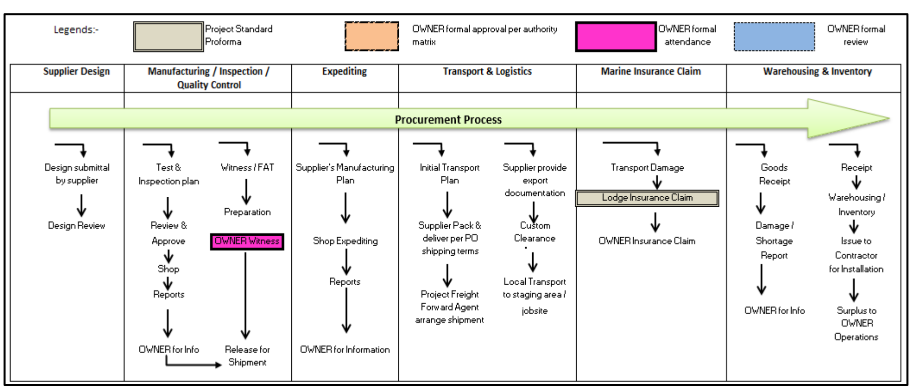
There are conceptual similarities between manufacturing and construction, when comparing materials management. The activities of procurement, planning, and cost control are sensibly the same between both construction and manufacturing industries. For instance, purchasing (pre-award processes) and procurement (post-award) including expediting, logistics to from the suppliers to the site/shop are identical. Figures 2.9, 2.10 and 2.11 illustrate the activities of purchasing and procurement which are similar in both construction and manufacturing industries.

Figure 2. 9
Pre-Award Purchasing Process



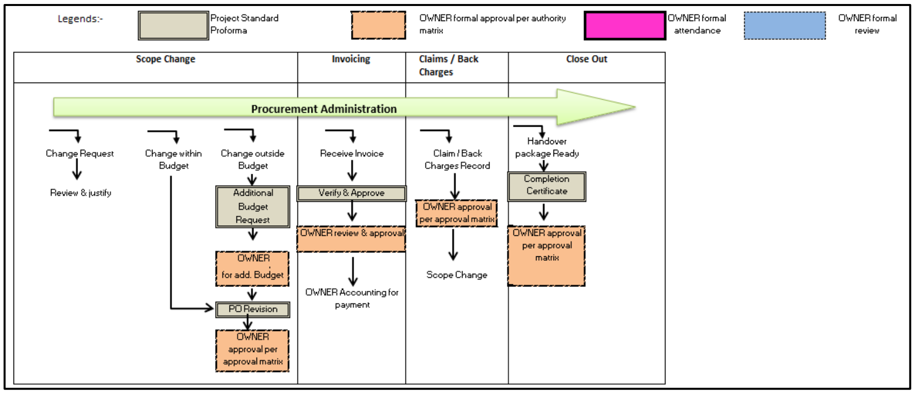
Dany Julien (2019)

Figure 2. 10
Post-Award Procurement Process



Dany Julien (2019)

Figure 2. 11
Post-Award Procurement Administration



Dany Julien (2019)

The researcher observed several purchasing and procurement similarities between construction and manufacturing industries. For instance, they are:

- Purchasing activities in both manufacturing and construction include a pre-award process with stringent ethical procedures for selecting bidders based on commercial, technical and pricing;

- Purchasing seeking optimal purchase costs in regard to category sourcing;

- Procurement activities including post-award processes in both manufacturing and construction. These activities are negotiated with the objectives to reflect the highest quality products, and delivery on-time at the lowest transportation expenses;

- Cash flow strategies are common to both manufacturing and construction industries throughout all phases of project management;

- Long lead procurement for equipment or materials are dealt the same ways between manufacturing and construction staffs;

- Planning and controlling material flows between constructions or manufacturing are not much different from one another (Ibn-Homaid *et al*., 2001). The dates for field installation in construction are synchronized with respective materials /equipment lead time of acquisition; whereas in manufacturing, the shop installation dates are in lined with the procurement lead time and labour requirement;

- Like manufacturing's Master Plan System (MPS), the construction industry utilises Bill of Materials (BOM) as part of their materials/equipment requirement;

2.3.2. Differences between Construction and Manufacturing

The fundamental differences that exist between the construction and manufacturing processes have made it difficult to directly apply supply chain principles to the construction industry (Young *et al.*, 2011). In general, manufacturing productions are planned, fixed and predictable, whereas the activities of constructing are, although planned, very flexible in nature, dynamic and changeable.

Daily activities in construction mega-projects are non-routine (never the same), non-repetitive (differ every day) and one-time unique undertaking with a discrete time and financial objectives. Therefore, projects are different from one to another, and exact duplication of activities are hard to identify. Hence, the researcher noted the following differences in construction and manufacturing industries:

- Mega-projects don't have the same rigid and predictable structure of those in manufacturing;
- Mega-projects can't be reproduced nor can't be standardized from project to project. However, pre-fabrication planning in some trades (e.g. structural modular, power stations, etc.) can be duplicated, if planned respectively;
- Mega-projects are discontinuous (ending will happen) and non-repetitive;
- Material deliveries in manufacturing are often repetitive from weeks to weeks and months to months, whereas materials delivered to a construction site, vary from day to day;
- Material deliveries in manufacturing are homogenous, continuous, and repetitive. Planning is less difficult and more stable in manufacturing;
- Material deliveries in construction are heterogeneous from project to project or system to system (Ibn-Homaid *et al.*, 2001). Planning in construction is very dynamic and faces constant changes;
- Scheduling in manufacturing is less volatile than to the one in construction;

- Contrary to the static nature of manufacturing's Master Plan Services (MPS), Bill of Materials in construction will change, evolve and progress throughout the project;

- Because of the non-repetitive environment in construction, material ordering systems like MRP, VRP or JIT that are popular in manufacturing, cannot be used to generate a material process, without being modified continually;

- Delivering materials to a construction mega-project is different than when delivering to a manufacturing plant (Silver, 1988; Tah, 2005; Young *et al.*, 2011). Delivery of materials are homogeneous, routine, repetitive, and less disruptive in a plant, whereas delivery materials in construction can be chaotic with little standardisation amongst sub-contractors;

- Over similar period, the numbers of purchase items in a mega-project are considerably higher when comparing to a manufacturing's MPS;

- Manufacturing enjoy data gathering and accuracy where variables are systematically recorded and controlled throughout the life cycle of sourcing, making, delivering and returning processes;

- Construction industry rarely produce process data, and moreover, data analytics has not reached the pre-infantile phase in that industry. In other words, construction analytics is mostly inexistent, except for using basic statistics formula when procuring progress reports. Construction analytics offer great research potential.

- Supply chain network in manufacturing attempt to achieve optimal transparencies through membership, ownership and empowerment. On the other hand, construction stakeholders within a project have different objectives in sight (Dainty *et al*., 2001). Hence, the construction culture does not entertain the same sense of membership, transparency, ownership and empowerment amongst their stakeholders;

- Information networks in manufacturing are created and improved throughout time by constant inputs and update from their participants. IT investments are conducted over time. The diversity of stakeholders during mega-projects are often characterised by the inclusion of large, medium and small contractors and suppliers, all working on different information technology (IT) platform. Therefore, the commonality of short-term duration for projects and large number of stakeholders with different financial status, do not favor large capital investment in building a network of information technology (IT) during mega-projects;

- Knowledge transfer is also well integrated in the manufacturing industry. Network participants will share their positive and negative experience in an effort of continuous improvement and transparencies. On the other hand, knowledge transfer is impeded by the short-term and uniqueness nature of mega-projects. In fact, stakeholders will often be reluctant to convey information between them, with the objective to position themselves, ahead and against each other's (Jang *et al*., 2009);

- In terms of cost control, owners wish to minimize project costs, whereas contractors and unions halls are looking at increasing their revenues on each project they take part in. Therefore, controlling cost in construction is constantly an uphill battle amongst several stakeholders.

2.4. MATERIAL MANAGEMENT

Managing material flows properly at construction site has become its own profession. The Construction Industry Institute (2015) defines material management as an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, and are obtained at a reasonable cost, specified in a timely manner, are obtained at a reasonable cost, and are available when needed. Likewise, Muehlhausen (1991) described the activities of material management as part of the design of the structure, material requirement and project planning, requisitioning of materials, purchasing materials, expediting shop drawing approval and material fabrication and delivery, shipping the material, receiving the material at site or other storage location and strong and handling materials.

Jang *et al*. (2009) report the definition of material management by the Business Roundtable as "the management systems that leverage the efficient utilization of materials and equipment with all necessary efforts to ensure that the right quality and quantity of materials and equipment are appropriately controlled in a timely manner with reasonable cost and availability". Once work is completed, materials will be disposed as surplus, transferred as spares or simply sold at re-stock values or dispose them as scraps. Hence the overall objectives of material management in construction are:

- To optimize the material flows when arriving at construction sites;
- To lower procurement costs;
- To reduce labour inefficiency by having the materials and equipment in the right place at the right time, ready for installation when needed.

A critical aspect of a large project is the allocation of resources (LEM – labour, equipment, materials), as stated by Smith-Daniels *et al*. (1984). The materials and equipment purchased during a project are an important cost factor during the construction phase. Silver (1988) broke down the project costs as followed:

1. Materials (including equipment) accounts for 35% to 60% of the overall costs of a project;
2. Construction labour accounts for 30% to 40%;
3. Indirect management can cost up to 20% percent with engineering costs at 15%.

Plemmons (1995) states in Torrent *et al*. (2009) where they found the two most influential factors over material management were material availabilities and construction time lost directly associated with materials that are missing, damaged or not available for installation. Even though materials accounts for 50% to 60% of the project costs (Ibn-Homaid *et al*., 2001; Kini, D, 1999; Torrent *et al*., 2009; Young *et al*., 2011), the focus on controlling material flows and labour employment through a complete supply chain process are not, as opposed to manufacturing, a priority in job sites' reports progress, as observed by the researcher of this doctoral thesis.

2.4.1. Material Planning in Manufacturing

Operational planning in manufacturing is driven by a Master Plan System (MPS) and related materials requirement, assembly time and labor associated with them. The sequences of manufacturing operations are dictated by the availability of materials worked at a preceding operation. The ordering process (Push & Pull) in a manufacturing operational environment works where a component at a lower level must be finished before production of the one using it at the higher level of the same production line. Planners that are working in manufacturing plants can employ various ordering models and calculates min/max inventory and optimize their inventory carrying cost.

The MPS relies on product structure, where the product-material relationships can be used to calculate the quantities and times of producing a specific product. Consequently, materials and operations schedules are intertwined and generated concurrently in a single process (Ibn-Homaid *et al*., 2001).

Supply chain literature is replete with studies evaluating the effectiveness of various order/reorder techniques (Ibn-Homaid *et al*., 2001; Ala-Risku *et al*., 2005; Bell *et al*., 1987). For instance, planners will utilise the Economical Order Quantity (EOQ) technique, in which ordering materials at various levels of the production line are schedule sequentially. Enterprise Resources Planning (ERP), Material Requirement Planning (MRP), Vendor Replenishment Planning / Vendor Managed Inventory (VRP / VMI)), Just-in-Time (JIT) and Kanban (Lean Management) are also common methods used in delivering materials to manufacturing plants on time, on budget, and with the highest quality possible. Other techniques are discussed in literature ranging from heuristics and serials methods to algorithms, but these ordering techniques have not yet been proven to be practical for mega-projects (Smith-Daniels *et al*., 1984).

2.4.2. ERP

Enterprise Resources Planning is a system of integrated applications such as planning, accounting, finance, sales and marketing, logistics, distribution and operational components of the organisation. These integrated applications allow the organisation to manage the business between suppliers, the organisation itself and the clients, into a single data base, application and user interface. Essentially, ERP is a newer version of an MRP system.

The researcher, while working at corporate level or during the construction phase, noted that several project owners and large prime contractors worked with SAP ® and Oracle ® systems as their exclusive ERP systems. However, the researcher further observed these ERP systems were never integrated between project owners and their prime and sub-contractors. Reasons for using the same ERP platform, but not being shared by either one was based on confidentiality and competitive advantage.

2.4.3. MRP

The abbreviations MRP has been used to signify systems called Material Requirement Planning (MRP I) or Manufacturing Resources Planning (MRP II). In a simple way to explain the sequence, MRP I did develop into MRP II over time, with the addition of financial, marketing and purchasing components. The basic logic of MRP is a simple process that begins with customers and how well the organisation can supply their demand (Stock *et al.*, 2001).

Materials or equipment are obtained through a master schedule, which check demand against on-hand inventory, schedule receipts and planned order release for production. The process of checking and ordering materials is called explosion. MRP works best when safety stocks are also implemented in the explosion process. Today, MRP systems have been replaced by ERP.

Material Resources Planning may be the preferred work for the first part of a construction project. However, they may end up being the worst ordering technique near the end of the same project as complexity takes over, and changes are dealt better with Just-in-Time (JIT) techniques, especially for rush orders.

2.4.4. VRP / VMI

In a Vendor Replenishment Planning (VRP) / Vendor Management Inventory (VMI) approach, the suppliers are given visibility and full transparency to upcoming material needs (Chopra *et al*, (2007). VRP/VMI makes suppliers more pro-active by informing the buying organisation of potential delivery problems. In this instance, the suppliers are given full responsibilities to deliver the materials on time to the construction site for each Bill of Material. By knowing the latest information, such as construction delays or advancement, the construction's planners can adjust their activities; consider the material constraints and warned the suppliers to adjust their productions. The technique of VRP/VMI works well in manufacturing since it integrates transparent supply chain processes across its network.

VRP/VMI is common amongst construction leasing companies like United Rentals Leasing, who will establish a leasing store for equipment, right at the construction site. Here, the contractors can lease and return their equipment at the store once finished using them. This allow the contractor to reduce the cost of leasing equipment, which the saving is subsequently passed to the owner of the project. VRM/VMI is also used in construction where inventory is kept at the vendors' premises. These virtual warehouses assist projects in keeping the inventory at no cost, preserved the equipment by the vendors and prolonged the warranty period until received at sites.

2.4.5. JIT

Just-In-Time (JIT) systems are utilised when demand is continuous and uniform. Under the JIT approach, products, components, or other materials are delivered at the precise moment an organisation needs them, or as close to the moment of installation as possible (Stock *et al.,* 2000). JIT system is a preferred approach in manufacturing since variables are known and predictable. Overall, JIT is an inventory management philosophy that attempts to minimize inventories through the elimination of safety stocks (which MRP keep in stocks). At the heart of JIT system is the notion that anything over the minimum amount necessary for a task is considered wasteful.

JIT in construction will work when purchasing hardware (bolts, washers, coupling, gaskets, etc.) that are recurrent and non-expensive. Similarly, bulk materials such as cement and earth filling will be purchased with precise installation dated. One last example where JIT will work is for leasing equipment, such light towers and heat blowers. In this case, the contractors can rent the equipment directly at site and return them as soon as they are finished with them.

On the other hand, tag equipment which are purchased as long lead or short lead items, will render JIT system non-practical for construction purposes. One reason for not using JIT with tag equipment, is that very often, they are based on a conception design. Thus, their time of production, forecasted during the concept phase, will change as the production move to the right. Another reason for not using JIT system with long and short lead tag equipment is because lead time can be accurately forecasted.

2.4.6. Kanban

Kanban and JIT systems have become very important in manufacturing in recent years. Kanban is basically a system of supplying parts and materials at the very moment that they are needed in the factory production process, so those parts and materials are instantly use (Stock *et al.,* 2000). Kanban approach, like JIT are seldom use construction.

2.5. PLANNING IN CONSTRUCTION

The level of materials ordering in construction varies between the various phases of the project. First, material ordering during the pre-feasibility – PFS (concept, front-end planning) is almost non-existent except for the exploration missions and environmental activities conducted by biologists, environmentalists, geologists and mining engineers.

Procurement of materials and equipment starts usually during the final feasibility phase (detailed engineering) with long lead items being treated first. Procurement activities will remain active during the construction phase. Materials and equipment arriving at a construction site can be a highly dynamic process, since materials and equipment can come from a variety of sources (i.e.: suppliers, contractors, owners) located across the world. These sources will have numerous effects on the overall schedule, depending on their date of arrival (ETA) and dates of installation

The major challenges in material planning occurs during the construction phase, where effective material management will have a net increase in productivity level. So, the success in managing materials during mega-projects will depend on the ability to deal with uncertainty and changes created by these material flows. For instance, material management at construction site will behave the following ways:

- First, due to time constraint, suppliers of equipment and materials don't usually go through the process of pre-award/post award bidding processes. Instead, most often, suppliers are selected based on time-delivery commitment instead of cost. The philosophy behind this approach is based on a fact that large number of workers can't be sitting idle or slow down and wait for equipment / materials to arrive at construction sites;

- Second, the supply chain network as operated in most industries is fragmented during the construction phase. Purchases of materials can be procured by owners and any of their contractors at sites, whomever has the greater ability to get the materials or equipment faster. Hence, material ordering, material tracking and cost correlation between materials, labor and installation dates are not accounted as accurately as they are tracked in the manufacturing sectors;

- Third, where materials, labours and schedules are intertwined and inseparable in manufacturing, activity scheduling in construction are at first developed during detailed engineering (feasibility phase), followed by even more adjustments throughout the construction phase. In a sense, work schedules will evolve throughout the project;

- Fourth, operational planning in construction do not use the planning techniques employed in manufacturing such as EOQ, MRP, VRP, JIT and Kanban (Lean Management). Hence, the fixed and predictable sequencing activities in manufacturing is not possible during the construction phase.

As a result, the sequential activities from construction planning are not dictated by the back-to-back scheduling that we notice in manufacturing. Rather, construction activities are planned in accordance with materials lead-time and are constantly revised based on the latest information available, such as site congestion or transportation delays, crane availabilities, material and equipment availabilities and labour availabilities. Finally, contrary to manufacturing industries, the accuracy for the amount of certain materials and equipment at the beginning of the construction phase may change as the execution of the project move forward.

Evaluating the best order/reorder methods in construction is obviously not that simple. It is the inherent presence of demand variability in the construction industry that has made the application of supply chain techniques such as MRP, VRP, JIT and Kanban difficult to apply (Young *et a*l., 2011). Their advantages and benefits vary amongst them.

2.5.1. Dealing with Uncertainty

Uncertainty about demand and lead-time in manufacturing is dealt with using safety stocks. In construction, for instance, planners will often procure bulk materials and add a simple 5% to 10% contingency factor (safety stocks). Subsequently, the concept of zero inventories promoted in a JIT approach is confronted in construction (Han *et al*., 2008). Thus, it is perceived by the construction industry that having a certain level of material buffers is an effective way of mitigating the risks associated with any number of possible uncertainties that may arise in the delivery of materials at construction site (Smith-Daniels *et al*., 1984; Young *et al*., 2011).

Another buffer observed in the construction sector relates to time delivery of materials. Typically, where projects are constructed in remote locations, materials may arrive at sites at least four (4) to six (6) weeks ahead of time. Here, the cost of holding inventories at site for a long period of time has no financial importance in the eyes of commercial managers in construction.

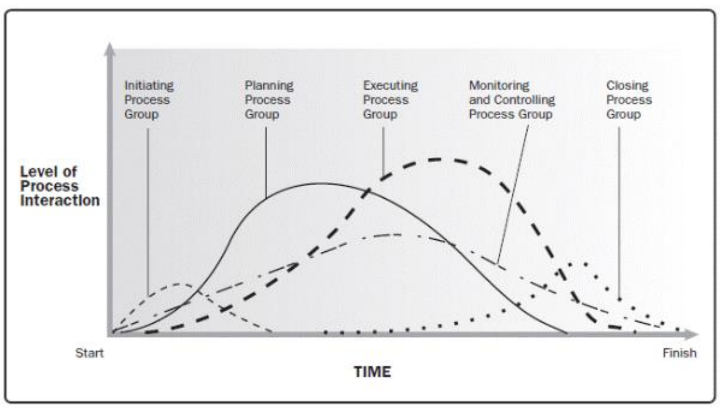
Buffer materials can also protect incompetency. In fact, a lack of inventory control for surplus materials and equipment were observed during this research. Chapter Four –

section 4.2 Inventory Control illustrates the inaccuracy of material inventories being accounted at a construction site.

2.5.2. The Last Planner Method in Construction

Project management is the practice of initiating, planning, controlling and closing a project scope into a final product. A project will have a scope with a define scope and a defined beginning and end. Project Management Institute (PMI) is one of the most recognized global organisations that promotes education and standards amongst project professionals. PMI describes the project lifecycle under five stages: (a) initiating, (b) planning, (c) executing, (d) monitoring + controlling, and (e) closing. The PMI's project lifecycle is described below in Figure 2.12.

Figure 2. 12
Project Lifecycle - PMBOK

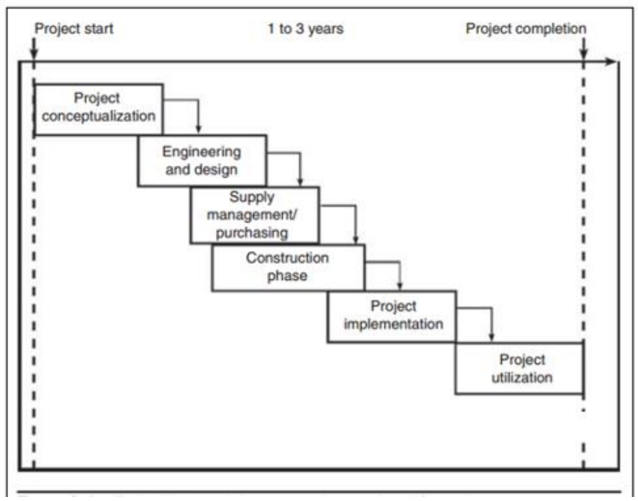


Sanghera (2006)

As oppose to operations which are stable and predictable, projects are temporary in nature and stands in contrast with operations. Therefore, planning for manufacturers can become are repetitive, permanent or semi-permanent functional activities which produce products or services. Activities in manufacturing revolve around maintenance and operations, activities of repairs, shutdowns or upgraded projects. Furthermore, manufacturing planning is supported by supply chain management such as procurement, transportation and logistics. Bill of materials (BOM), schedule of installation, and lead time for procurement are important variables in manufacturing planning.

Similarly, Benton *et al.* (2010), described the six (6) project lifecycles, in such ways: (a) conceptual, (b) engineering design, (c) procurement, (d) Construction, (e) implementation and at last, (f) utilization. Benton' project life cycle is presented in Figure 2.13.

Figure 2. 13
Project Lifecycle – CPSCM



Benton *et al.* (2010)

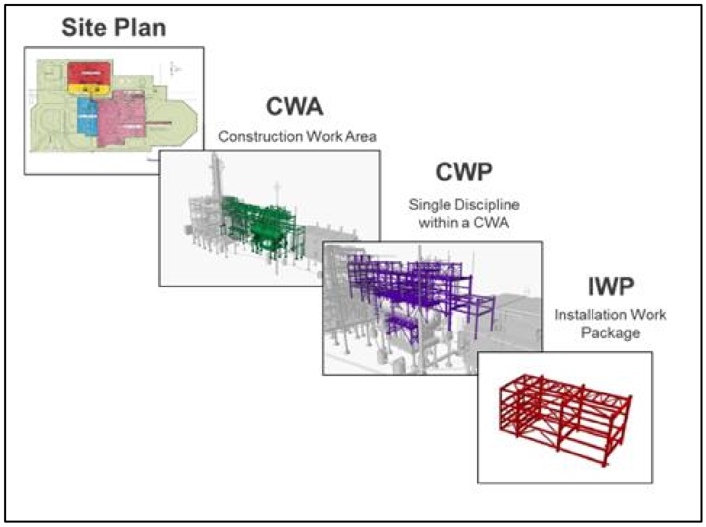
Planning activities for mega-projects will resemble to the manufacturing's ones involved with repairs and upgraded projects. Overall, planning in project engineering and construction management are more complex than planning in manufacturing. Accordingly, such prevalent project management methods such as PMBOK, from the PMI, have been stated as inadequate for controlling the progress of construction projects (Ala-Risku *et al*., 2005; Choo *et al.*, 1999).

Therefore, emerging project management methods are becoming an important key aspect to deliver materials on time during mega-projects. In fact, the traditional long-term project management methods are applied too often in a general manner, leading to poor short-term planning, since no plan can ever be detailed enough to enable the mere execution without feedback from the environment (Ala-Risku *et al*., 2005).

The Last Planner Method has been presented as an alternative to general methods. The Last Planner Method, as illustrated in Figure 2.14, use a general project management framework, however the detailed day-to-day construction activities are managed by a less stringent framework that is cognisant of the actual daily progress and requirement for the project. Henceforth, the Last Planner Method presents a near-term scheduling model that depicts the progress of the project it operates in, and continuously updates it to represent the most likely timing for the project activities to come (Ala-Risku *et al*., 2006). Subsequently, the Last Planner, which is an individual, will have the most accurate demand information available regarding labour, equipment and materials. Thus, the Last Planner with its up-to-date knowledge is to ensure the final preparation are in place for all the prerequisites needed for performing a distinct construction task before it gets assigned to a working group.

Typically, planning activities for construction mega-projects will be geographically divided into several areas of construction known as Construction Work Areas (CWA). Each of these areas will correspond to physical locations most likely related to buildings or process areas to be constructed. For instance, assuming they are five areas to be built in a project, each area will be named 001-CWA, 002-CWA, 003-CWA, 004-CWA and 005-CWA. Figure 2.15 depicts the creation of a planning package from the beginning (CWA) to the end (IWP – Installation Work Package)

Figure 2. 14
IWP Method



Ala-Risku *et al*. (2005)

In a sense, each CWA will be numerically associated to corresponding Engineering Work Packages (EWP) and one Construction Work Package (CWP). For instance:

- The EWP is essentially an engineering deliverable that is used to develop a Construction Work Package (CWPs). EWP are documents in the form of drawings, procurement deliverables, specifications and suppliers' documents. From a defined scope of work, EWP provides the functionality of the equipment and materials to be installed in each area. For instance, EWP will describe the size, speed, mechanical and electrical output of a conveyor;

- Each CWP is numerically related to an EWP. Although very similar to EWP, CWP should include working instructions and sequence of field installation in order to assemble all equipment and materials that are described in its respective EWP. For instance, the conveyor describes in the EWP, will be lay on a specific concrete foundation with a specific MPA, installed at a specific height, away from the wall at a specific distance, etc.;

- Subsequently, each CWPs will also be sub-divided into further micro-packages known as Installation Work Package (IWP), which are deliverable for construction crews that enable them to perform quality work in a safe, predictable, measurable and efficient manner;

- IWP is defined to be manageable and progress-able, typically of limited size such that a crew can complete the work in about two weeks (500 to 1000 hours / 6-men team) or a shift rotation. Each IWP possesses its own bill of materials (BOM) and the actual flows of materials. The activities of IWP are described in Appendix C.

In essence, planning in manufacturing is repetitive and predictable, whereas planning in construction often changes due to Request for Information (RFI), Site Instructions (SI), Change Orders (CO) and missing materials or equipment. The Last Planner Method presents a near-term scheduling method that depicts the daily progress of the project it operates in; and continuously updates to represent the most likely timing for the project activities to come (Ala-Risku *et al*., 2006).

2.6. THEORIES RELATED TO CONSTRUCTION MANAGEMENT

This research over the years evolved from the freedom of adopting various methodologies and theories, while maintaining the same research objectives.

The route which the researcher chose to select various methodologies for this thesis are detailed in Chapter Three. Conversely, this section below details the history of why the researcher chose a theory during a specific timeline for its research. Subsequently, the researcher adopted the method of selecting several temporary kernel theories. The term kernel theory refers to any descriptive theory that informs an artifact (Gregor *et al*., 2007).

At first, the Resources-Based View (RBV), was looked as a suitable theory by the researcher. While the researcher was employed by an engineering firm, specializing in mining construction; the researcher was for the first time, introduced to mega-projects. Having worked in supply chain manufacturing for several years and knowing the importance of integrating all departments into one supply chain process, the researcher quickly realized the managerial problems in the construction industry weakened its competitive advantage against foreign engineering & construction (E&C) companies bidding in Canada.

Hence, the RBV was utilized in order to investigate if the engineering firm possesses heterogeneous resources that identify assets, capabilities and competencies with the potential to deliver superior economical competitive advantage. While reviewing literature in sustainable competitive advantages, the researcher diverted away from the RBV's internal organizational strategies and focused its reading on the Dynamic Capability Theory (DC Theory).

The DC Theory is also a theory of competitive advantage, which takes for account both rapidly changing external and internal environment. The researcher reconciles the internal explanations of RBV and how it informs and complements construction's external market positions. In a sense, the DC Theory covers both internal and external factors. DC Theory is covered in section 2.6.2.

While being deployed at various construction sites, the researcher quickly realized the construction industry also lagged most industrial sectors in integrating management information systems. So, making a statement that engineering and construction firms are late adopters or lagers of IS during mega-projects is a construct that cannot be denied by anyone who has worked on mega-projects. Trying to understand why the construction industry lagged into IS integration, the researcher, through the Theory of the Adoption of Information Systems, investigates three (3) elements:

- The reasons why mega-projects were late adopters or lagers of implementing information systems (IS);

- Does being late adopters or lagers of IS correlate with the construction industry's managerial problems during mega-project?

- Does being late adopters or lagers of IS make construction companies less competitive?

Then, the researcher combined the fourth and fifth theory to its research: The Co-Alignment Theory and the Contingency Theory. Understanding that construction mega-projects are complex and hold many variables, implementing BI tools in mega-projects must find the right fit and be correctly aligned with the various construction stakeholders.

Then, the last theory to be investigated for this thesis is the Structuration Theory of Duality. Construction job sites, especially the ones involved in mega-projects are social systems which have patterns (design, weather, labour, etc.) that change over time and can be studied beyond the realm of human control with a positivistic approach, or by the social action created by the social system and analysed with a subjective (interpretivist) approach. So, the question arises where the selected methodology should be of quantitative nature, qualitative, positivist or subjectivist, or even all of them; when observing mega-projects. The researcher understands the Structuration of Theory of Duality cannot be expected to furnish the moral guarantees that critical theorists or positivists wish to obtain by proving or disproving theories. Detailed of the Structuration Theory of Duality is described further in this chapter.

Finally, the researcher looks at all of the theories, views or approaches described above and attempt to formulate a kernel theory that gulp them all, as well as reports an important real-world managerial problem in a unique or innovative way. This last methodology selected by the researcher is the Design-Science Research (DSR) and described in the Chapter Three: Operative Framework.

2.6.1. Resources-Based View

The Canadian construction industry is now faced with global competition and is no longer protected by its borders. Faced with these global threats, the Canadian construction industry must develop excellent capabilities and do things in a superior manner, if it desires to sustain a competitive advantage. Achieving a sustainable competitive advantage lies at the heart of much of the strategic management literatures and strategic marketing (Barney, 1991).

Resources-Based View (RBV) is perhaps the most influential framework in strategic management that is widely used to understand competitive advantage (Sangari *et al.,* 2015). The RBV is interdisciplinary in that it was developed within the disciplines of economics, ethics, law, management, marketing, supply chain management and general business, such as construction (Hunt, 2013). RBV focuses its attention on an organisation's (owners or contractors) internal resources as a means of organising processes (e.g. integrated supply chain in project management) and obtaining a competitive advantage against competitors.

Wernerfelt (1984)'s article titled "*A Resource-Based View of the Firm*" was pivotal in establishing RBV as an influential body of work in research. Wernerfelt's work was further reinforced by Lippman *et al*. (1982); Barney (1986) and Barney *at al*. (1986). Other concepts, as business science progress were later integrated into the resource-based framework.

Barney (1991), Barney *et al*. (2001), Graighead *et al*. (2003), Matta *et al*. (1995), and Ray *et al*. (2004) describe the Resources-Based View as an organisation with a unique bundle of resources (tangible – e.g. software; intangible – e.g. foremen experience), and suggests that sustained competitive advantage can only be derived from those resources that become: a) valuable, b) rare, c) imperfectly imitable and e) not substitutable.

Organisations need to find those resources that can sustain a position barrier in which they are alone; and where they have good chances of being among the few who succeed in building one (Wernerfelt, 1984). Then, a sustainable competitive advantage is obtained when an organisation implements its technological strategy not simultaneously implemented by many competitors. Hence, in order to relate to the new reality of global competition, a construction organisation which build mega-projects, will have to develop unique, firm-specific internal core competencies that will allow them to outperform global competitors by doing things differently. Internal organisation and network knowledge, for instance, are resource positions that are complex and not easily appropriated by competitors since they are embedded within a culture and a network.

In summary, an organisation must create a situation where its own resource position makes it difficult for others to catch up (Rungtusanatham *et al*., 2003 and Wernerfelt, 1984).

2.6.1.1. Resources & Capabilities

According to the RBV, an organisation delivers sustainable competitive when resources and capabilities are managed such that their outcomes cannot be imitated by competitors, which ultimately creates a competitive barrier (Mahoney *et al*., 1992). An organisation' resources include all assets, organisational process, organisation's attributes, knowledge, information, etc., controlled by an organisation that enable it to conceive and implement strategies that improves efficiencies and effectiveness (Barney, 1991). A variety of authors have described the term resources. Wenerfelt (1984) simply describes resources as anything which could be thought of a strength or weakness for a given organisation. On the other hand, Barney (1991) describes resources in three (3) categories:

- Physical (capital) resources: include technologies, equipment and materials, etc., used by an organisation, as well as its geographical locations. Physical capital resources are tradable and non-specific to the firm;

- Human (capital) resources: include the training, expertise, relationships, etc., of an organisation;

- Organisational resources or capabilities: include by which an organisation plan, control, and coordinate various systems as well as informal relationship among group.

Views and explanation of the RBV was also described by Grant (1991), which stated that the foundation of an organisation's long strategy rests upon two premises:

1. First, internal resources and capabilities provide the basic direction for an organisation's strategy;

2. Second, resources and capabilities are the primary source of profit for an organisation. Hence, the supporter of the RBV would argue that a construction organisation should look inside its company to find the sources of competitive advantage instead of looking at competitive environment.

Other authors have proposed other categories of resources. For instance, Grant (1991) described resources under six categories: financial resources, physical resources, human resources, technological resources, reputation and organisational resources. Either we consider more definitions of resources, a key ingredient to being competitive is the ability of an organisation to achieve cooperation and coordination amongst organisation's stakeholders.

The resources itself do not confer any advantage for a company, if it's not organized to capture the value from them. Only the construction companies are capable to exploit the valuable, rare and imitable resources can achieve sustained competitive advantage. Note there can't be strategically equivalent substitutes for these resources and capabilities that are valuable, but neither rare nor imperfectly imitable (Barney, 1991). A construction company that has valuable and rare resources such as site procedures and work packages, can achieve at least temporary competitive advantage until a competitor copies them.

Authors like Feisher *et al.*, 2015, which necessarily seek temporary sustainability, are conveying on concepts around being near impossible to gain and maintain sustainable advantage. Moving over the competitive ladder, a construction organisation which acquires a supply chain technology will obtain temporary competitive advantage until the other competitors acquire the same technology. RFID in construction is an example where organisations using this technology have observed a cost reduction to material management; whereas other organisations who still track materials manually don't enjoy the same advantage.

Besides an organisation's resources, the RBV also explores the concept of the organisational capability. Capabilities are firm-specific, organisationally embedded, non-transferable, and specific to the organisation whose purpose is to improve the productivity of the physical and capital resources possessed by the organisation (Hein *et al*., 2014). Creating capabilities involve complex patterns of coordination (routine) between people and other resources or within an organisation's network (Grant, 1991).

Hein *et al*. (2014) defined capability as the ability to perform a task or skill with or without a set of performance criteria. A capability is a routine or a number of interacting routines (Grant 1991). Itami (1987) also described these unique managerial skills as invisible and intangible assets for an organisation's management team (e.g. construction management team). These organisational capabilities are therefore hard to imitate (heterogeneity), hard to transfer (immobile) and enable an organisation to achieve sustainable competitive advantages.

High cost to imitate capabilities due to imperfection can arise from several sources: geography, expertise knowledge, organisation specific resources and capabilities. Capabilities are in a sense a combination of complex routines, based upon tactics and internal knowledge fused to the organisational culture. On the other hand, high cost to imitate resources (replicability) are easier to achieve and become more transferable than capabilities.

The researcher believes that one way to achieve this level of organisational capability is by seeking analytics during construction. These data would perform value-creation for both construction organisations and their stakeholders. Craighead *et al*., (2003) simply stated the value in an organisation is created when performance increases or when decrease costs. A formula for the value creation is presented by the researcher in Figure 2.15.

Figure 2. 15
Value Creation

$$\text{Value} = \frac{\text{Performance}}{\text{Cost}}$$

Dany Julien (2019)

Furthermore, Hein *et al.* (2014) measured capability by checking whether the sufficient conditions for executing the tasks are satisfied, such as:

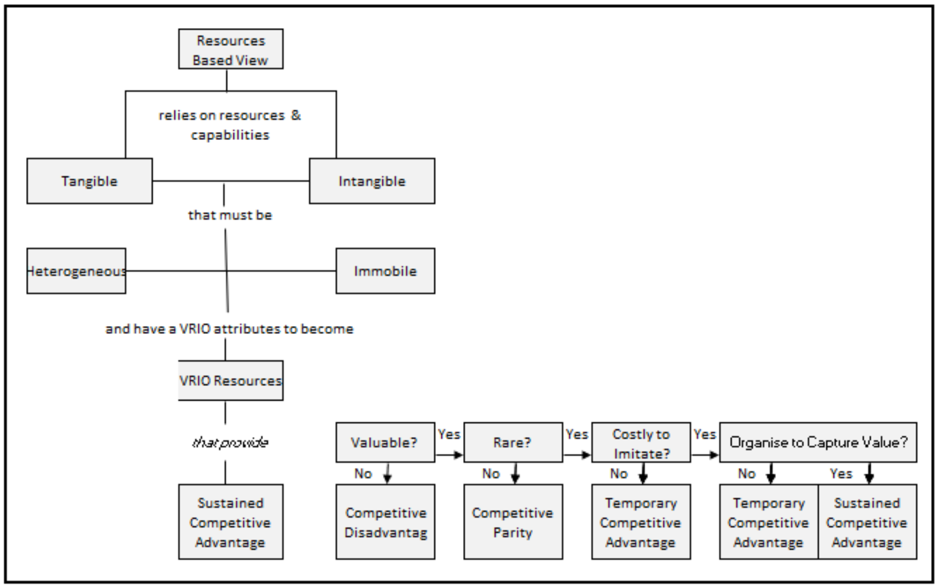
- Adequate resources (people, tools, and information), processes (activities and routines) and priority (guided decision-making) exist;
- Collecting evidence by performing the same tasks;
- Collecting evidence based on sampling;
- Collecting evidence based on task similarity.

Overall, resources are stocks of available factors that are owned or controlled by the organisation whereas capabilities refer to an organisation's capacity to deploy resources, usually in combination using organisational processes to affect a desired end (Barreto, 2010).

2.6.1.2. Heterogeneity

The RBV regards the organisation as a collection of resources and capabilities that are derived internally from factors such as its assets, skills, knowledge or culture (Wernerfelt, 1984). Barney (1991) and Matta *et al*. (1995) describe in Figure 2.16, the framework on the RBV model. Barney's (1991) RBV assumes two assumptions in analyzing sources of competitiveness. First, the RBV model assumes that organisations within the industry must be heterogeneous with respect to the resources they control. Second, the RBV assumes these resources are immobile across the industry they operate in, and thus heterogeneity will be long lasting.

Figure 2. 16
RBV Framework



Barney (1991)

An organisation will achieve resource heterogeneity when it possesses a resource or capability that is not currently possessed by any of the competing organisation. For instance, organisational routine, such as Wal-Mart's integrated supply chain and high-level coordination is an example of tactic knowledge that are developed over time and hard to imitate. Some capabilities may derive from one resource, while other routines require highly complex interactions involving the cooperation of many different resources (Grant 1991), such as the integration of multifunctional departments within the same organisation.

Organisations investing in ERP, SAP and Oracle, can be misled by wanting to achieve a competitive advantage with such systems. Thus, investing millions of dollars in implementing these ERP does not automatically provide an organisation with sustainable competitive advantage since every major competitor can acquired them. The competition between Apple Inc. and Samsung Electronics is a good example of how two companies that operate in the same industry and thus, are exposed to the same external forces, but are achieving different financial performance. In a nutshell, Apple appears to be better at designing user-friendly products and sells its products at much higher prices because of its branding. As a result, Apple reaps higher profit margins than Samsung.

An example of heterogeneity in construction management would be the implementation of construction analytics for measuring individual or team performance at construction sites. For a construction company to introduce analytics in its operational corpus would be considered most likely as First Entrant in the industry, it can be assumed to provide a heterogeneous advantage to this company.

2.6.1.3. Immobility

ERP providers like SAP and Oracle never agree to sell exclusive rights of their products or services to one organisation. In fact, ERP providers will use their lessons-learned from implementing their ERP systems in various industries and transfer their new knowledge to other clients, for their benefits. Thus, keeping key proprietary knowledge immobile is practically impossible when dealing with these global ERP providers. Hence, keeping competitive advantage out of sight or hands of competitors has become more difficult than ever before and obtaining competitive advantage is difficult when working in a global environment (Flesher et al., 2015; Gonzalez, 2011; Matta *et al*., 1994). Moreover, workforce mobility, supply chain transparency and the Internet of Things have made it hard for any organisation to keep secrecy.

The second assumption of RBV is that resources can’t be mobile and do not move from company to company, at least in short run. By implementing this immobility approach, companies can’t replicate rivals’ resources and implement the same strategies. Additionally, organisations without resources (or capabilities) will be at costs disadvantages, when attempting to obtain new technologies against organisations that already have them. So, organisations with these heterogeneous resources or capabilities are said to have resource immobility. Intangible resources, such as brand equity (Apple, Nike), processes (Dow Chemical), knowledge (Harvard University) or intellectual property (Coke) are usually immobile. On the other hand, a resource or capability that is mobile or easy to copy, a competitor without that resource (or capability) face no cost disadvantage in developing it or acquiring that resource (or capability) from someone.

The previous section presented the heterogeneity of implementing construction. The same is true with the implementation of analytics supported by data warehousing acquired at multiple construction sites; would provide a tremendous competitive advantage and subsequently, make it harder to transfer the knowledge. These resources and capabilities would be unique to a project, and the historical knowledge could be transfer into other projects. Hence, construction analytics is also view as a strong potential for resource immobility.

2.6.1.4. VRIO Resource Test

RBV assumptions (heterogeneous and immobility) can only achieve sustainable competitive advantage, once a resource or capability has been established with the VRIO Resource Test. Reed *et al*., (1990) described competitive advantage as the unique position which an organisation develops against its competitors through patterns of resources deployment, cost strategies and product differentiation.

In a way, Reed *et al*., (1990) suggest that competitive advantage ensues from competencies. As such, competencies and competitive advantage are independent variables and performance is the dependent variable. Porter (1985), on the other hand differs from this view. Rather, Porter (1985) saw competitive advantage (dependent variable) as the objective of a strategy and achieving this advantage will automatically result in higher performance for the organisation. Porter (1980) defined two types of competitive advantage an organisation can achieve relative to its rivals: (1) lower costs and (2) differentiation.

Sustainability is in its most basic sense, an advantage kept over a period of time. Some authors have suggested that a sustainable competitive advantage is simply a competitive advantage that lasts a long period of calendar time (Barney, 1991, Porter, 1985). In such, an organisation will deploy its resources and capabilities aiming to achieve a sustained advantage for the longest time. However, sustainability in the context of sustained competitive advantage is not always time related per se. According to Lippman et al. (1984), a competitive advantage is said to be sustained when competitors in the industry have ceased any attempt to duplicate the strategy sought from the leader.

Moreover, a long period of time, a competitive advantage will erode both through the deprecation of the advantaged organisation's resources and capabilities and through imitations by rivals (Grant, 1991). For instance, Blackberry phones were unable to sustain its competitive advantage over Apple and Samsung. The speed of erosion will depend on how well the resources and capabilities are managed by all competitive organisation. The durability of the sustainability will also vary from industries such as technological organisations which are faced with dynamic changes every day.

Overall, sustainability over time will also depends on the organisation to be able to protect strategic imitation from other organisations in the same industry. Thus, according to several authors (Barney's, 1991; Flesher et al., 2015; Gonzalez, 201; Matta *et al*., 1994, Reed *et al*., 1990), a sustainable competitive advantage can be attained if the resources and capabilities are:

1. Value-creating is achieved when the resources or capabilities exploit opportunities and/or neutralize threats in an organisational environment. Resources are valuable if they help organizations to increase the value offered to the customers, such as an Apple phone versus a Samsung phone. This is done by increasing differentiation or/and decreasing the costs of the production;

2. In terms of construction, value can be created by improving materials tracking, correlating the flow activity of material movement with cost analysis and derivate analytics from the time of reception to the time of installation. The researcher also

believes that implementing a supply chain approach to project management can potentially provide value-creation;

3. The resources or capabilities are said to be rare and cannot be simultaneously implemented by any current or other potential competitors. Resources that can only be acquired by one or few companies are considered rare. When more companies have the same resource or capability such as ERP (SAP and Oracle), they simply have competitive parity. The researcher believes that construction analytics obtained at sites supported by historical data from other previous jobs will provide a rarity that that is unknown to competitors in the industry. The researcher believes that construction analytics can be obtained, if a supply chain approach is introduced to project management procedures;

4. When resources or capabilities are costly to imitate, they become subsequently imperfectly imitable, and other organisations will be unable to duplicate them. A bank of historical data pertaining to materials versus labour costing, performance KPIs, productivity KPIs, analytical trends and so on, will be harder to imitate as data warehousing and analytics will provide non-imitable data.

According to Gant (1991), for an organisation to imitate the strategy of a competitor, it must understand the transparency of that organisation. In a sense, the rival organisation must establish the capabilities which underlies the rival's competitive advantage, and then it must determine what resources are required to replicate these capabilities. Nonetheless, copying internal processes among competitors are hard to achieve in a real business world. In fact, most resources and capabilities are not freely transferrable between organisation, unless outright takeover. In such cases, perfect imitations are nearly impossible.

Very importantly, managerial skills are too often taken for granted as invisible assets. Managerial skills are socially complex processes and depend on interpersonal skills between all construction stakeholders. They are often developed over long period of time and may involve hundreds of thousands of small decisions that cannot be imitated (Castanias *et al*., 1991). The development of managerial skills also includes the ability to conceive, develop and exploit supply chain systems and analyze processes in order to support and enhance other business functions. Overall, these managerial skills are hard to imitate, they are highly immobile, and create a level of ambiguity to anyone trying to copy them due to their social complexities. Thus, managerial skills can provide a source of sustained competitive advantage, especially through this causal ambiguity.

For instance, Wal-Mart developed in the early 70's a PID (purchase / inventory / distribution) system. Over the last forty (40+) years, this internal PID system has been modified and improved, to provide Wal-Mart a persistent and sustainable competitive advantage over companies like Target and JC Pennies. It is in fact, Wal-Mart’s managerial skills and its *savoir faire* that have become over the years as a source of sustained competitive advantage, generating large financial profits.

The researcher believes that only when construction organisations will elect to apply supply chain approach and analytics, similar to Wal-Mart, IBM, Apple and others, that they will gain sustainable competitive advantage.

2.6.1.5. Causal Ambiguity & Imperfections

Causal ambiguity or imperfection refers to an undefined cause or relationship between a resource and its performance consequences (Canon *et al*., 2008). It exists when the link between the resources controlled by an organisation and the same organisation’s sustained competitive advantage is not understood or understood only very imperfectly (Barney, 1991).

Porter (1985) argued that barriers to imitation are never insurmountable, but some barriers will be higher than others and therefore more difficult for rivals to overcome. Thus, the sustainability of the winning edge is determined by the strength of not letting other firms compete at the same level. Another reason that an organisation’s resources may be imperfectly imitable is that superior organisation are socially and culturally complex, beyond the ability of an organisation to systematically manage or influence. When competitive advantage is based in such complex social phenomena, the ability of other organisations to imitate these resources is significantly constrained (Barney, 1991).

Thus, the inability of competitors to understand what causes the superior performance of a rival organisation helps the latter to reach and maintain a sustainable competitive advantage for a period. Ambiguity or imperfection comes in many forms for both the decision itself and the decision-makers (Fleisher et al., 2015).

Coding routines and decoding unstructured patterns into patterns makes what seems ambiguity to one, an advantage to another decision-maker. Thus, decoding ambiguity can be a potent barrier to any competitive imitation and allow for the competitor to sustain their advantage for a longer period (Dierickx, I *et al*., 1989; Fleisher *et* al., 2015).

Thus, causal ambiguity creates an important barrier to imitation and would limit the outsiders to imitate value added services from a leading construction organisation. Under condition of causal ambiguity, it is not clear that resources that can be described as the same resources that generate a sustained competitive advantage, or whether that advantage reflects some other non-described organisation resource (Barney 1991). In order for causal ambiguity to be a source of sustained competitive advantage, competing organisations must have an imperfect understanding of the link between the resources controlled by an organisation and an organisation's competitive advantages (Lippman *et al.,* 1982).

The researcher believes that integrating a supply chain approach combined with analytics when conducting mega-projects will promote knowledge ambiguity against a competitor. In fact, supply chain integration is the root to produce strong analytics during mega-projects, and analytics is at the heart of creating causal ambiguity, only to be understood by the construction organisations implementing supply chain approaches into mega-projects. A project being unique and non-routine, accompanied with current analytics and historical statistics will make imitation costly to any construction competitors. Implementing a supply chain framework with construction analytics during the execution of a mega-project would provide data warehousing that would be stored as causal ambiguities. Finally, causal ambiguity can also have negative effect within an organisation. Having difficulty in decoding ambiguity makes it difficult for an organisation to improve in performance.

2.6.1.6. Capabilities & Competencies

The term capability and competency are difficult to distinguish. As described earlier in this section, capabilities are firm-specific, organisationally embedded, non-transferable, and specific to the organisation whose purpose is to improve the productivity of the physical and capital resources possessed by the organisation (Hein *et al*., 2014). Creating capabilities involve complex patterns of coordination (routine) between people and other resources. A capability is a routine or a number of interacting routines (Grant 1991).

In the literature, competencies are often described as more elemental whereas capabilities aggregate competencies in a whole value chain (Hein *et al*., 2014). The introduction of Core Competency was made by Prahalad *et al*., (1990) in their article titled "*The Core Competence of the Corporation*". The authors illustrated that core competencies lead to the development of core product, which further produced end products for end users. According to the same authors, core competencies is developed as a collective learning across a corporation, not individually based learning or skills, through the process of continuous improvements. The framework of competencies is described by several factors:

- Not easy for competitors to imitate;
- Can be reused widely for many products and markets;
- Must contribute to the end consumer's experienced benefits from the value of the product or service.

Reed *et al.* (1990) suggest three (3) characteristics of competencies: tacit, complexity and specificity:

1. Tacit knowledge is accumulated through experience and is disorganized and hard to decode, informal, and generate ambiguity through the operator's own level of unawareness (Reed *et al.* 1991);

2. Complexity arise from several sources such as organisational routine, rare resources and capabilities, and is influenced by organisational cultures. Thus, core competencies that are complex generate ambiguities;

3. Williamson (1985) identified four types of assets specificity: site, physical asset, dedicated asset and human asset.

Hein et *al*., (2014) also provided two (2) different types of competencies:

1. Competency-enhancing innovation: it sustains or improves an existing competency, like Apple's line of intelligent phone;

2. Competency-destroying innovation: it makes an existing competency obsolete, like the introduction of computer instead of calculators for doing calculations.

Finally, the research conducted by Danilovic *et al.* (2007) defined core competencies under five (5) elements:

1. Core competence is the way work is performed, the ability to coordinate diverse production skills, to integrate and harmonized multitude of skills and technologies into products that deliver value to customers;

2. Core competencies are the glue that binds existing business and the engine for new business development (Prahalad *et al.,* 1990);

3. Core competence is a combination of complementary skills and knowledge bases embedded in a group or team providing a superior product (Coyne *et al.,* 1997);

4. Core competence must be linked to end products (difference with capabilities);

5. Core products can be used in several different combinations and end products.

In summary, competencies may come from various resources and are within the organisation's control. Competency is internal to an organisation and produced the way an organisation utilised its resources and capabilities in a superior manner against its competitors. Arguably, the most effective barriers to imitation are achieved when competitors don't comprehend the competencies on which the advantage is based upon (Lippman *et al*., 1982).

2.6.1.7. Sustainability & First Entrants

Implementing a strategy such as introducing a supply chain approach into a mega-project would be considered a first mover /first entrant in the construction industry. By doing so, the researcher believes a construction organisation would have some insights about the opportunities (measuring real-time performance and productivity, controlling budget and schedule delivery) associated with implementing such a strategy (Lieberman et al., 1988).

Nevertheless, the followers on the other hand, will find it easier to adopt the same technologies due to the spread of the knowledge (mobility). The risk for an organisation to invest first (First Entrant) is sometimes higher than the risk to wait and follow (Lieberman *et al*., 1988). Therefore, an organisation will need to keep growing its technological capability from its resources and supply chain integration in order to protect its position and move up the competitive ladder (McFarlan *et al*., 1981; Wernerfelt, 1984). This is due to fast changing technologies which eliminate the potential of long period of sustainability (Kim *et al*., 2006).

For instance, being the first one to introduce a supply chain framework, accompanied with RFID, RTLS or any other Auto-ID systems, and filter the information through data analytics, will provide the adoptive organisation more advanced knowledge than the organisations which still manually track materials at construction site. These organisations may gain access to better understand the flow of materials at sites, develop a positive and innovative reputation within the industry, all before any organisations which implement their strategies later in time.

2.6.1.8. Competitive Advantages in Construction

The Resources-Based View attempts to understand under what circumstances one or multiple resources will lead to a higher return for the organisation in terms of immobility, heterogeneous, causal ambiguity, and value creation. The Resources-Based View (RBV) determine if organisations are going to sustain competitive advantages over a long period of time. Consequently, mega-projects which adopt the RBV perspective should be beneficial for all construction stakeholders, especially project owners and contractors. In summary, implementing the Resources-Based View in a construction setting understands the following facts:

A. Resources' capabilities are a complex interactions and coordination of people and other resources (materials) needed to conduct a project;

B. Construction sites are a collection of resources and capabilities that are derived internally from intangible factors such as its assets, skills, knowledge or the employees' culture;

C. Construction sites are a collection of tangible assets such as ERP and general assets used to conduct daily business;

D. Construction organisations are comprised of several stakeholders, including project owners, E&C, contractors, union halls and vendors;

E. Construction analytics can only be obtained in mega-projects when an organisation choose to implement a supply chain approach where material and labour are the base root for coding, analysing and storing the information in data warehouse.

2.6.1.9. Criticisms of the Resources-Based View

Priem *et al*. (2001a, b) led the criticisms of the Resources-Based View. According to them, the Resources-Based View reflects a unique feature, namely that sustainable competitive advantage is achieved in an internal environment where competition does not exist. In other words, the sustainability of the winning edge is determined by the strength of not letting other firms compete at the same level. In addition to Priem *et* *al*. (2001a, b), many other authors (Dierickx *et al*, 1989; Ma, 2003; Priem *et al.*, 2001a, b) raised the following key criticisms on the Resources-Based View:

1. RBV is focused only on internal analysis and forget to take for account the negative effect of the external forces;

2. The RBV applies to static environment only. Hence, RBV is considered to be essentially static in its nature and inadequate to explain an organisation's competitive advantage in changing external environment;

3. It is almost impossible to find a resource which satisfies all RBV's sustainability criteria (heterogeneous, immobile, value-creation, rare, hard to imitate and organise to create value);

4. An organisation cannot manage a resource or capability that it does not know it exists, thus causal ambiguity is nullified;

5. Purchase assets (physical resources) cannot be sources of sustained competitive advantage just because they are purchased;

6. RBV is not a theory since the condition of empirical content, nomic necessity and generalized conditionals are not met. According to Dubin (1978) and Fry *et al.* (1987), a theory require: a) construct or variables of interest, b) congruence, which is the set of laws of relationship among constructs or variables, and c) boundaries within which the laws of relationship among constructs or variables, which they are expected to operate;

7. Contingency hypothesis within which the integrity of the system is maintained but in a markedly different condition;

8. RBV is tautological or self-verifying. In this case, the RBV has defined a competitive advantage as a value-creating strategy, that is based on resources that are among them valuable;

9. RBV is anti-competitive (Ma, 2003); since the moment competition becomes active, competition advantage becomes ineffective since two or more organisations begin to perform at a superior level, evading the possibility of a single organisation dominance;

10. The concept of resource rarity is not necessary because the implications of the other concepts (valuable, inimitable and non-substitutability) are inherently rare;

11. The lack of defined time for sustainability makes it difficult to empirically test the period of sustained competitive advantage;

12. The internal perspective of the RBV is in stark contrast to strategic frameworks which emphasize positioning a firm with respect to external factors, for example Porter's Five Forces (Hein et al, 2014).

However, construction organisations and their leaders are not interested whether the RBV constitute a theory or not. Rather, they require guidance for achieving competitive sustainability or survival. So, the existing Resources-Based-View, as criticized in the previous paragraphs, focuses on internal resources and capabilities, and may not be adequate to facilitate the current external factors such as global threats. In this case, the organisational theory of Dynamic Capability is probably better suited to meet today's global forces. Thus, an organisation should exploit its current resources and capabilities (i.e. internal analysis: strengths and weaknesses) and develop new set of resources and capabilities to sustain its competitiveness in future market environments (i.e. external analysis: opportunities and threats).

2.6.2. Theory of Dynamic Capability

In today's global market, most construction companies must navigate through turbulence and high-velocity markets. External threats are real and Canadian construction organisations face them globally. For instance, mining companies which are headquartered in Canada have had the flexibility of building their new projects overseas or in Canada, depending of the economics. These companies will conduct their business cost analysis by analyzing many variables. The final decision is most likely the final cost of building and operating them. So how can Canadian construction organisations maintain a competitive advantage against these global threats, when our costs of labours are not comparable to some other countries?

Dynamic Capability (DC) Approach is based on competitive survival from external threats rather than achieving of sustainable competitive advantage within its own internal resources and capabilities (i.e. Resources-Based View). Historically, the philosophy of the Dynamic Capability (DC) derives from the Resources-Based View (Nelson *et al.*, 1982; Sangari *et al.,* 2015). The DC approach is more in line with today's construction industry's realities facing external threats and poor performance in completing projects on time, on scheduled and on budget.

These external threats can be addressed by leaning on the Dynamic Capabilities (DC) Theory, presented by Teece *et al.* (1997). The authors proposed that DC is based on competitive survival rather than achieving of sustainable competitive advantage sought in the RBV. This approach is more in line with today's construction business realities which face global competition.

The basic assumption of the Dynamic Capability's framework is that core competencies should be used to modify short-term competitive positioning, which can be eventually used to build long-term sustained competitive advantage. Hence, Teece *et al*. (1997) provide a bridge between the economics-based strategy literature and the evolutionary approaches to organisations (Douma, 2013). Teece *et al*. (1997) proposed the dynamic approach as an extension of the RBV (Barney, 1991).

Teece *et al.* (1997) defined the theory of Dynamic Capabilities as the organisation's ability to integrate, build and reconfigure internal and external competences to address rapidly changing environment. The environment around the construction industry are changing at fast pace, yet construction stakeholders working in construction mega-projects have not been able to adapt to these changes.

Similarly, to the RBV, capabilities are emerging as externally focussed whereas the competences are internally focussed and viewed as antecedents of the capabilities (Sangari *et al*., 2015, Teece *et al*., 1997). The dynamic capabilities' approach was built upon several concepts:

1. The "nature" of the concept is based on "agility" which is a special kind of capabilities. Agility leans on alertness and responses at three (3) corporate levels (strategic, operational, and episodic). Agility is based on the capacity to: a) sense and shape opportunities and threats; b) seize opportunities; and c) to maintain competitiveness through enhancing, combining, protecting and when necessary, reconfiguring the business organisation's intangible and tangible assets;

2. The "role" is the desired product for the dynamic capabilities is being able to integrate, build and reconfigure internal and external competences;

3. The approach focuses on a special type of "context": rapid changing environment such as hypercompetitive and high-velocity environment;

4. The dynamic capabilities are typically built, rather than bought and their "creations" are embedded in the organisational process and culture;

5. The organisational knowledge generated resides in new patterns of activity, in "routines" or in a new logic of organisation;

6. Competitive advantage may also require the integration of "external activities" through alliances, partnerships and technologies;

7. Like the RBV, the dynamic capabilities are "heterogeneous"; except that two philosophical thoughts exist:

    - Teece *et al*. (1997) implicitly or explicitly assumed that dynamic capabilities are essentially firm specific and unique;

    - Whereas Eisenhardt *et al.* (2000) asserted that dynamic capabilities exhibit commonalities across organisations. They justified the emergence of such commonalities as a result of the existence of multiple, similarly effective ways of performing the tasks ascribed to the dynamic capability (Barreto, 2010).

Teece *et al.* (1997)'s approaches explicitly state that a sustained competitive advantage is a direct outcome of dynamic capabilities. Other authors like Eisenhardt *et al*. (2000) have shown less confidence in the compulsory and direct link between dynamic capabilities and performance. In other words, dynamic capabilities are not directly linked to the organisation's performance. Instead, dynamic capabilities may influence performance through modifying an organisation's bundles of resources or routines (Barreto, 2010). Furthermore, Eisenhardt *et al.* (2000) asserted the potential for long-tier competitive advantage lies not only in the ability to change existing resources but also in doing it sooner.

Similarly, to the RBV, the view of dynamic capabilities does face several criticisms. The main construct of interest in the Dynamic Capability (DC) is the definition itself.

For some, the definition of DC is vague and illusive, mysterious and confusing, abstract and intractable and obscure or tautological (Barreto, 2010). The critics of the DC is based on the nature of the construct as being a big tent which allow varying degrees of dynamic capabilities in order to be more compatible with real-world situations.

According to theory purist, Dynamic Capability is not a theory because it shows no congruence of a theory. For instance, dynamic capabilities have been characterized by sets of work that are less than coherent in terms of the relationship between capabilities and performance. One critical approach state direct relationship between an organisation's dynamic capabilities and their performance or competitive advantage (Teece *et al*., 1997). A second critic proposes that dynamic capabilities don't necessarily lead to superior performance or competitive advantage (Eisenhardt *et al*., 2000). Finally, a third critics is contended that what should be considered is an indirect link between dynamic capabilities and performance (Zott, 2003).

In fact, for the purist, a theory must specify its boundaries as they are crucial and determine the limitations in applying a theory (Barreto, 1991). Dynamic capabilities' criticisms state the lack of boundary knowledge related to: a) the kinds of environment in which the dynamic capabilities are most relevant, b) the types of organisations that are most likely to benefit from the dynamic capabilities. Thus, for the theory purist, the Dynamic Capability is viewed as a big tent.

In terms of the "environmental criticisms", empirical studies should explicitly compare the effects of similar dynamic capabilities in two or more clearly distinct environmental conditions (e.g., different industries or different period of time).

In terms of types of organisations, literatures have not stated the pertinence of the dynamic capabilities in specific sectors, such as public organisations, multinational enterprises, new or already established organisations, small, medium or large organisations, etc. However, the researcher believes the DC approach describes well the external threats, of which the construction industry faces. The views of Teece *et al.* (1997)'s explains how a construction company will achieve competitive survival rather than achieving sustainable competitive advantage, through the Dynamic Capability.

Dynamic Capability stresses the fact that organisations with higher levels of dynamic capability should present higher levels of performance; however, critics state that there is no assurance that such a potential is realized by each organisation, and that no expected results can be forecasted. To counteract this positivism view, Ludwig *et al.* (2011) emphasize that DC focuses on the actual process of dynamic building such by a design rather than generate some type of abstract theory.

In this case, the researcher believes the Dynamic Capability was a good stepping board before introducing the Design-Science Theory. Thus, an organisation should exploit its current resources and capabilities (internal analysis – strengths and weaknesses) and develop new set of resources and capabilities to sustain its competitiveness in global environments (external analysis – opportunities and threats).

2.6.3. Theory of the Adoption of Information Technology

As supply chain networks are expanding globally, the adoption of any information technologies (IT) will differ in when, how and why organisations should choose to adopt them. There is literature evidence where the construction industry is generally considered slow to adopt new management information technologies (Khalfan *et al.,* 2006). According to KPMG's "Building a Technology Advantage – Global Construction Survey 2016," when it comes to technology innovation, just 8% fall into the cutting-edge visionary category, while 69% are considered either followers or behind the curve.

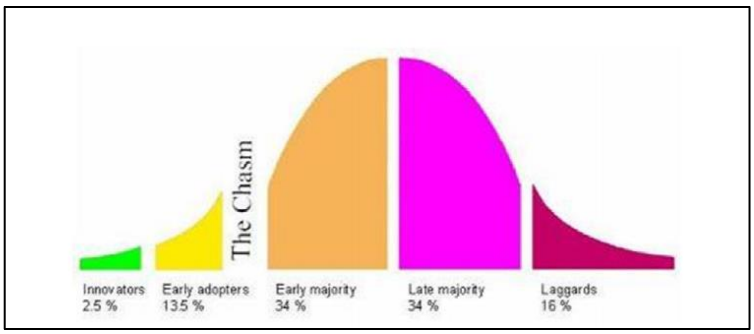
We know that adopting information technologies (IT) in construction require considerable investment and effort to be successfully applied during projects (Chae *et* *al*., 2010). Attempting the integration of real-time reporting during the execution of mega-projects are perceived today, as a monumental task amongst construction stakeholders. This is largely because construction organisations tend to use multiple software platforms that are silo- monitored and disconnected. In fact, where all the projects the researcher worked for, the construct which was observed was the costs and risks of adopting new technologies during each project outweighs the perceived benefits. Hence, status quo in integrating information technologies at construction site remains the reality and the effort to step from a laggard toward late majority still needs lots of convincing amongst construction senior managers.

Information technologies focus on improvements in the efficiency, accuracy, and the security of materials and information flows, whether across a supply chain network spread globally or within an organisation's internal operations (Canon *et al.*, 2008). There are many studies that demonstrate supply chain technologies facilitate traceability, providing real-time inventory and greater collaboration across the supply chain (Canon *et al*., 2008). The same benefits can be transferred while managing materials at construction sites. Subsequently, the vast amount of literature brings the opportunities to link theories. For this research, the following theories were reviewed:

- Theory of Diffusion of Innovations (DIT) by Rogers (1995);
- Theory of Task-Technology Fit (TTF) by Goodhue *et al*. (1995);
- Theory of Reasonable Action (TRA) by Fishbein et *al*. (1975);
- Theory of Planned Behavior (TPB) by Ajzen (1991) with the Decomposed Theory of Planned Behaviour by Taylor *et al.* (1995);
- Technology Acceptance Model (TAM) by Davis *et al*. (1989); along with the Technology Acceptance Model 2 (TAM2) by Venkatesh *et al*. (2000); Davis *et al*. (1996,); and Technology Acceptance Model 3 (TAM3) also by Venkatesh *et al.,* (2008).

First, the Theory of Diffusion of Innovation (DIT) was proposed by Rogers (1995). The theory focuses on innovation acceptance and adoption. The Theory of Diffusion of Innovation explains that the innovation and adoption of a technology by an organisation (e.g.: construction firm) or a person (e.g.: project director). This theory explains the adoption of IT over several stages including: a) understanding, b) persuasion, c) decision, d) implementation, and e) confirmation. This theory led to the development of Rogers' (1995) S-Shaped adoption curve with categories including innovators, early adopters, late majority and laggards. The S-Shape adoption curve is shown in Figure 2.17. When comparing the construction industry to IT adoption, the industry is for the most part categorised as a late majority or a laggard.

Figure 2. 17
Innovation Adoption Curves

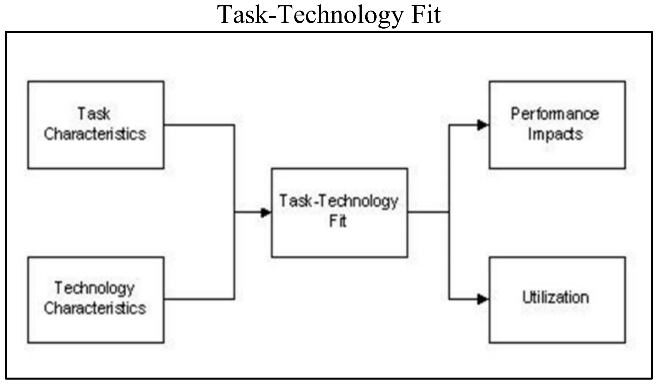


Rogers (1995)

The second IT theory which is investigated for this research is like Rogers (1995)'s Theory of Diffusion of Innovation (DIT). This second IT theory is led by Parasuraman *et al*. (2001) as the Theory of Technology Readiness (TR). This theory refers to people's propensity to embrace and use of new technologies for accomplishing goals in home life and at work (Parasuraman *et al*. 2001). The authors similarly classified technology consumers into five technology readiness segments: a) explorers, b) pioneers, c) skeptics, d) paranoids, and e) laggards. In fact, these categories are like Rogers (1995) S-Shaped adoption curve of innovators, early adopters, early majority, late majority and laggards. In reference to TR, the construction industry are mostly laggards, paranoids and skeptical. Both Theory of Diffusion of Innovation (DIT) and the Theory of Technology Readiness (TR) are essential for understanding the organizational implementation success.

The third theory of adoption of information technology is the Task-Technology Fit Theory (TTF) composed by Goodhue *et al.* (1995). The Task-Technology Fit emphasizes individual's impact instead of the organisation. In this case, individual impact refers to improve efficiency, effectiveness, and/or higher quality. As shown in Figure 2.18, TTF investigates the actual usage of the technology. Goodhue *et al*. (1995) assumed that a technology must have an individual fit between task to be accomplished and technology characteristics, which will subsequently increase the likelihood of utilization and to increase the performance. The TTF is good for measuring the technology applications already release in the marketplace, such as RFID for material tracking or tablets with the capability of progress report for engineering and construction activities. The TTF is in line with the Co-Alignment Theory, which will be described later.

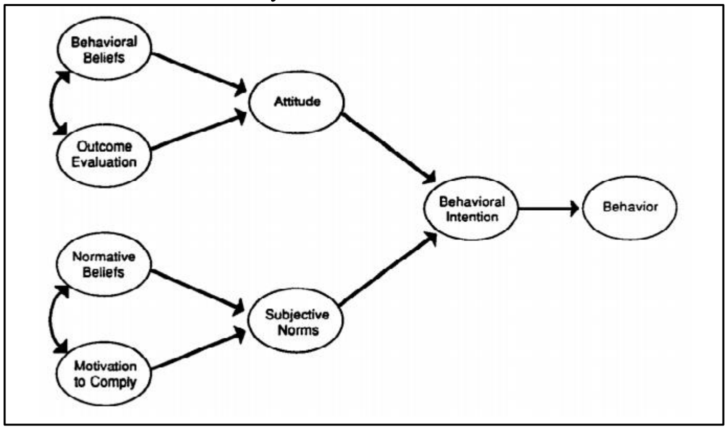
Figure 2. 18
Task-Technology Fit



Goodhue *et al.* (1995)

The fourth theory of adoption of IT is the Theory of Reasonable Action (TRA) developed by Fishbein *et al*. (1975). According to Lai (2017), this theory is one of the most popular theories used in IT adoption and is in line with the epistemology of subjectivism presented in this research. Hence, the Theory of Reasonable Action, as seen in Figure 2.19, is the person's subjective norms of what they perceive (Lai, 2017).

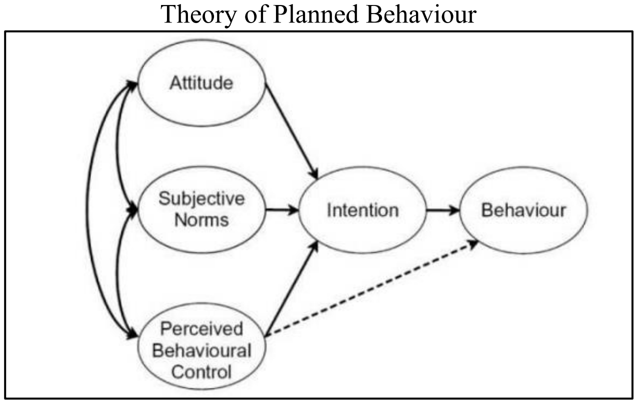
Figure 2. 19
Theory of Reasonable Action



Fishbein *et al*, 1995

The fifth theory of adoption of IT is the Theory of Planned Behavior (TPB) developed by Ajzen (1991). The Theory of Planned Behavior is about the behavioural intention of the person's attitudes toward that behaviour, as shown in Figure 2.20. Like the TRA, TPB focuses on the perceived behavioural control, which the users perceive its limit (Lai, 2017). The first two factors in TRA and TPB are identical in both theories. The third factor in TPB perceives behavioural control, which is the control which limit their behaviour (Lai, 2017).

Figure 2. 20
Theory of Planned Behaviour



Ajzen (1991)

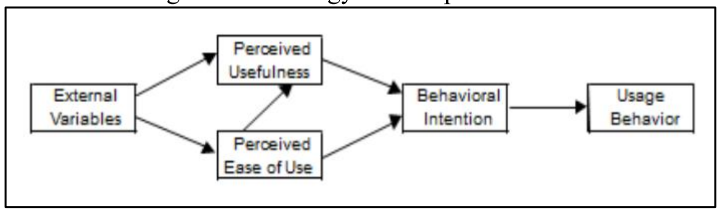
The perceived behavioural control is an important factor, especially when technology bring the effect of Big Brother is Watching You. The privacy acts protecting employees' right to confidentiality and not getting tracked against their knowledge, are prevalent in most occidental and European countries. For instance, the researcher encountered during his stay in the field some criticisms while using personal information obtained from employees' safety information, such as age, years in the trades, trade union name, province of origin, etc. Using the safety information included with the Advanced Work Packages (part of Workface Planning), the researcher was able to cue KPIs performance and productivity and obtain best and worst performance with the tradesmen.

The fifth theory is the Decomposed Theory of Planned Behaviour (Decomposed TPB) and was developed by Taylor *et al.* (1995). The Decomposed TPB consists of three main factors influencing behavior intention and actual behavior adoption which are: a) attitude, b) subjective norms, and c) perceived behavior control (Lai, 2017). Hence, someone who is trying to integration of IT will have better chance to convince senior management to invest in this adoption, if the three behaviour criteria are met.

The sixth and last theory of adoption which relates to the construction industry is the Technology Acceptance Model (TAM). It was first introduced by Davis (1986), and later upgraded into TAM2 by Venkatesh *et al*. (2000) and finally into the TAM3 by Venkatesh *et al*. (2008). The original TAM is described in Figure 2.21.

TAM was specifically designed to address the factors of IT acceptance by a user (Chau *et al*., 2002). The main findings of all acceptance models are the perception of the usefulness and perceived ease of use, which were found to have a direct influence on behaviour intention, and subsequently providing usage behaviour. According to Paul *et al.* (2003), TAM model is the most used framework in predicting IT adoption.

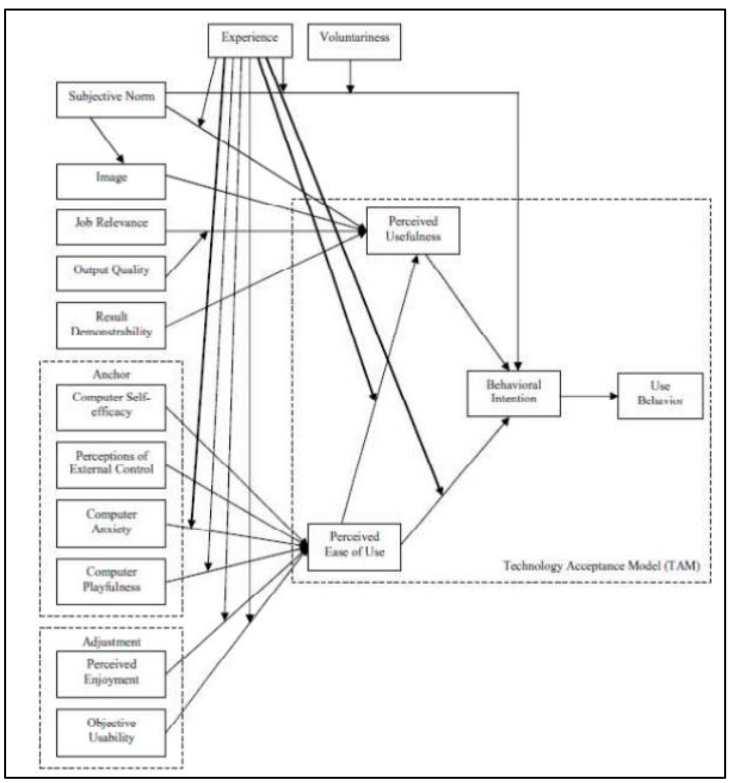
Figure 2. 21
Original Technology of Acceptance Model



Davis, 1996

The same authors of TAM developed TAM3 using the four different types including the individual differences, system characteristics, social influence, and facilitating conditions, which are determinants of perceived usefulness and perceived ease of use control (Lai, 2017). TAM3 presents a complete network of determinants which influence the users' IT adoption. TAM3 is presented in Figure 2.22.

Figure 2. 22
TAM3 Model



Vankatesh *et a*l., 2008

The notion that infrastructure technologies may not be the primary drivers of business values themselves, but rather create real options for additional opportunities (Curtin *et al*., 2007); such as gathering business intelligence, reducing tracking works and understanding work process. When investing in the adoption of information technologies in construction, it is critical that we understand how to construct the appropriate incentives to help ensure the technological investments are effective.

Adoption decision in construction projects require a clear understanding of which potential uses of information technologies are to be selected, and what expected benefits, costs, challenges and issues are associated with any of these technologies. The construction industry needs to become more innovative and able to provide greater value for money through introducing learning in their organisations. However, there are barriers that still exists when comes time to invest in information technologies at a construction site. For instance, participants in the semi-structured interviews stated the following:

- It is hard to sell integrated IT system according to one interview: "we will implement an IT system if we can see an immediate cost benefit to the owner, and if there is no immediate ROI, it will remain on the shelf for someone else to experiment with". Project managers are all about building, no proving solutions for a software integrator.

- It is hard to sell integrated IT system according to another interview: we know integrated IT is important, however, we require strict use of return on investment (ROI) for any related investment outside the project' scope of work". To date, however, very few initiatives have an ROI and therefore don't get funded.

They are also several challenges and issues when implementing supply chain's information technologies, including management, financial, organisational and technological. The following sections describe some of the barriers.

2.6.3.1. IT Culture

A significant embedded characteristic of the construction industry is a culture that resists change, especially with the adoption and diffusion of innovation and knowledge

(Maqsood *et al*., 2009). The overall construction culture is partly responsible to why integrated IT systems have yet been adopted and the industry remains a laggard. Furthermore, the lack of cooperation and transparencies amongst different stakeholders during mega-projects, the lack of sharing information, and the inefficient use of information technologies are other factors affecting the adoption of IT (Jang *et al*., 2009).

2.6.3.2. Uncertainty with IT

The information processing is a way by which organisations reduce the ambiguity and uncertainty which they may face. Uncertainty is a key factor influencing performance and an important measure of the operating environment. According to Gallear *et al*. (2013), uncertainties have a major impact on performance and managerial decision. In construction, for instance, the adoption of tracking technologies such as RFID, RTLS or WMS have a common objective of reducing uncertainty, which subsequently results from more accurate tracking and reduces incomplete and/or missing information (Canon *et al*., 2008).

Although information technologies in supply chain activities promise a level of reduction in uncertainty with respect to material management, construction companies have been reluctant to adopt these tracking technologies because of uncertainty regarding the payoff that will or might result from the adoption (Dutta *et al*., 2007; Reyes *et al*., 2007). According to Canon *et al*. (2008), the risks uncertainty related to the adoption of information technologies in supply chain activities can be grouped into two areas:

1. Uncertainty about the requirements and capabilities of the technology itself;
2. Uncertainty about the effects of the technology on inter-organisational relationships. Furthermore, these tracking technologies may not understand internal processes.

2.6.3.3. Investment Costs

Project owners like any other organisation are under significant cost pressures and are looking for easy ways to implement and to understand solutions that have been thoroughly tested and proven in the market (Smart *et al.* 2010). Today, a cost-benefit analysis for non-adopters is critical to the successful adoption of new technologies (Ngai *et al*., 2009; Wamba *et al*. 2009). Moreover, as long as the asymmetric distribution of costs and benefits remain across the supply chain network, construction partners such as unions, will have little incentive to adopt technologies when mandated by an owner.

Other organisations which have decided to adopt new technologies like RFID and tracking drones, are hoping to reduce cost through better inventory management and labour costs related to inventory and field expediting activities. Curtin *et al.* (2007) summarised a series of questions which an organisation should examine related to the (1) development, adoption, and implementation of information technologies; and (2) to use technologies within organisations and across its supply chain network, as well as (3) the related incentives and vendor relationships management issues. For instances:

1. Developing the business case for adopting a supply chain's information technologies that is relevant to construction sites' needs;
2. Understanding the adoption patterns and the complexity before selecting a final technology;
3. Implement new processes with the new information technology that is selected;
4. Technical integrations with other management information systems already in place;
5. Taking advantage of voluminous data collection, especially when dumping big data to construction stakeholders with different technologies;
6. Facilitating decision making capabilities in real-time.

Overall, adopting of information technologies will bring challenges and benefits for all construction's stakeholders during mega-projects. Issues, challenges or benefits will not make a difference in adopting these technologies if in the long run; construction stakeholders are not able to derive benefits from these technologies (Smart *et al.*, 2010). Nevertheless, despite the growing interests in information technologies in most industries, the success for implementing these technologies amongst construction stakeholders have not yet been proven.

2.6.3.4. Management Commitment with IT

Getting commitment from senior management is one of the biggest challenges in implementing new information technologies (Ngai *et al.*, 2009), and the construction industry is no exception to this rule. Information technologies are new for many organisations, especially in construction and widespread adoption of these technologies will continue to stall until managers in a position of responsibility for adoption decisions, can articulate the real business value within their organisations (Fosso Wamba *et al.*, 2008).

Expertise: Construction projects are unique by themselves, and finding local experts in implementing information technologies, specific to a construction project are rare; hence having programmers with some types of construction background are essential to promote a successful integration when adopting a new information technology. Evidently, the lack of expertise within the construction industry brings up the costs of implementation during construction projects, and may deter the widespread adoption of information technologies during mega-projects in construction.

Liability: Most of the organisations overlook the importance of having a legally binding master agreement before adopting new technology (Ngai *et al.*, 2009; Smart *et al.*, 2010). Liability limitations with a supplier and its functional team should be carefully discuss between all stakeholders involve during the information systems implementation. Ngai *et al*. (2009) noted in order to have a successful implementation, the authors believe that new technology needs to be royalty-free regarding future development of a management information system.

2.6.3.5. Financial Risks with IT

One of the most pressing issues when adopting information technology is the cost of implementation (Li *et al*., 2006; Ngai *et al*., 2009; Ross *et al.,* 2009; Smith, 2005; Srivastava, 2004). Implementation costs can range from $10,000 for the minimalist slap-and-play approach, to a fully integrated supply chain system that can cost tens of millions of dollars across multiple facilities (Ross *et al*., 2009). As an example, the consulting organisation A.T. Kearney estimated that major retailers will have to invest approximately $400,000 at each of their distribution centers, $100,000 at each store to read and manage data and $35-40 million to integrate their information technology such as RFID system into existing management information systems (Feder, 2003).

Cost uncertainty related to technological risks. This uncertainty will then increase costs of implementation during mega-projects. MacFarlane *et al.* (1981) have categorised cost uncertainties under several issues:

1. Failure to obtain anticipated technological results because of implementation difficulties;
2. Higher costs than anticipated at the end of implementation;
3. Longer time to implement than anticipated;
4. Technical performance below expectations;
5. Incompatibility with organisational hardware.

In the case of these issues, it is unlikely for an organisation to forward capital in order to implement technologies, especially in construction when a project is a one-time undertaking event, with a discrete short-time duration and capitals are concentrated in building, not IT.

2.6.3.6. Organisational Barriers

The benefits of information technologies in supply chain activities have their most effect when they are integrated into a wider inter-organisational context (Baker *et al*., 2009). The challenge of technological implementation comes from integrating ta new system with other functional database and applications (Angeles, 2005; Jones *et al*., 2004; Spekman *et al*., 2006) within an entire organisation.

Truer in the construction industry, integrating IT with an enterprise-wide application is still in the infancy phase. Construction organisations are faced with the undertaking of several projects each year and making data interface with related business applications such as material receivable, inventory management, productivity factors, timesheet for labour, etc. are costly to tailor-implement for each project. Hence, in the framework of Bunduchi *et al.* (2010), these authors were able to differentiate the organisational compatibility costs and technological compatibility costs.

2.6.3.7. Closed vs. Open Loop System

System openness is an important factor for the success of implementing an IT system related to supply chain during construction. According to Srivastava (2004), the main causes of supply chain inefficiencies are lack of collaboration, transparencies and visibility, which is typical of closed looping. The intra-culture of contractors, construction management teams and other construction stakeholders don't share transparency amongst individual reporting systems. The cause of this closed-loop approach often results in a bullwhip effect – an amplification of demand variability as the demand moves upstream and large data gets transfer at an exponential rate. This distortion of information can lead to excessive inventory and poor utilization of labour resources (Srivastava, 2004).

As supply chain's information technologies evolve in time, project owners and construction stakeholders will have to attempt to integrate some of their supply chain network in order to track materials and labour, through a share open network. Hence, to unlock the potential of information technologies beyond the boundaries of one organization, construction shareholders will have to work together and access the data generated by the use of supply chain technologies (Chuang *et al*., 2008; Smart *et al*., 2010; Smith, 2005; Srivastava, 2004). There can be many other reasons for an organisation to adopt a specific information technology and many independents variables may influence the relative importance on the rate of diffusion and adoption (Baker *et al*., 2009). Rogers (1995) states five reasons to adopt a new technology:

1. Relative advantage;
2. Compatibility;
3. Complexity;
4. Observability;
5. Traceability.

Chuang *et al*. (2008) also proposes several measurements of successes in relation to adoption and implementation:

1. Schedule reliability;
2. Budget reliability;
3. Business expectations;
4. Sufficient implementation time;
5. Vendor-consultant relationship;
6. Compatibility with legacy systems;
7. Management support;
8. Communication skills;

9. Full-time assignment;
10. Cross-functional team;
11. Interpersonal trust;
12. Project management skills;
13. Experience;
14. Business process knowledge;
15. Software product knowledge.

2.6.3.8. Concept of the Fit

Construction organisations act as interpretation systems for collecting data from job sites, interpreting or giving meaning to the data, and then learning by acting upon the interpretation (Daft *et al.*, 1984). Using the Co-Alignment Theory and the Contingency Theory, Khazanchi (2005), the two theories together address the issues of organisational-technology fit by asking when and under what conditions a construction organisation should adopt a new technology. The Concept of the "fit" is described by two (2) authors as:

- For one part, Van de Ven *et al*. (1985) imply that there must be a match between two theoretically related variables;
- Then, the "fit" is theoretically defined as a match between two variables that are independent of a performance measure and the closer the "fit" of the two variables, the higher the expected performance (Keller, 1994) and successful implementation.

Although researchers have identified success drivers for technological adoption and implementation, many questions that tie "technological fit" with contextual and structural variables are not fully understood (Khazanchi; 2005). The reviewed literatures by the researcher discussed which contingency factors (independent variables) are to be considered by a construction organisation, when evaluating the acceptability of a supply chain technology (dependent variable) in terms of its "fit" within a project.

Using the "Concept of the Fit" described by Van de Ven *et al*. (1985) and Khazanchi (2005), they described the notion of "Information Technology (IT) Appropriateness" as consisting of the conditions under which a construction organisation should consider itself a likely candidate for implementing a supply chain's technology, fitted for the project. The basic notion of the "IT Appropriateness" is that a proper fit between the complexity of a technology and the information processing activity of a construction organisation will result in high unit performance (Keller, 1994). Thus, the IT fit when adopting a new technology is a way by which organisations will reduce the ambiguity and uncertainty when faced with implementation.

Khazanchi (2005) measured organisational performance by assessing the impact of Electronic Data Information (EDI) on an organisation in terms of relative benefits realised through the adoption of a new technology. The same methodology for appropriateness could be duplicated with the adoption or rejection of a supply chain technology in construction. Khazanchi (2005) determined that four (4) critical factors had to be present in order to obtain "IT Appropriateness" and successful implementation: These factors are:

- Internal / external business and technological environment: This factor relates of the nature of the environment in which the businesses operate in. Construction industry is lagging in adopting IT, thus not a favorable environment;

- Organisational readiness and trading partner support: This factor support evidence that when participants in the same industry cooperate together, there is a stronger sense of technological implementation and information sharing, thus making the implementation more feasible for adoption There is little information transparency during mega-projects;

- Financial impact: If a construction organisation can generate substantial savings by using a new supply chain technology, positive financial impact will occur, making it easier to implement that new technology amongst stakeholders. A positive ROI, without any doubt, is required before an investment;

- Workflow productivity: This factor relates to the potential of implementing information technologies that can achieve enhanced workflow productivity for a construction organisation. Here, the supply chain technology would substantially reduce time and resources and by default, systematically increase revenues and reduce expenses.

In a similar study, Fosso Wamba *et al*. (2009) described the contingency factors (e.g. as operational and strategic benefits) directly or indirectly influencing the adoption of a new way of conducting business, such as integrating supply chain processes into construction management. These contingencies factors described in Fosso Wamba *et al*. (2009) were drawn from Venkatraman (1994):

- Environmental upheaval: This is the result in a change within the business environment once integrating new business supply chain process. Depending if the adoption is mandated or self-implemented, integrated supply chain process may inhibit or improve respectively the organisational learning level;

- Leadership: several authors make mention of the need to have executive management champion a project in order to make it successful. Without having a strong executive commitment from the top, especially when there is resistance to change such as within the construction culture, the integration will be a lost cause;

- Second-order learning: According to Fossa Wamba *et al.* (2009), second-order learning is the organisational capacity for an organisation to easily transfer its knowledge and technology to other organisations within its supply chain. Once again, the lack of transparency amongst sub-contractors during a project make knowledge transfer hard to achieve;

- Resources commitment: Many authors refer to the importance of having financial resources when implementing a new supply chain technology;

- Organisational transformation: Integration of a new technology or even a new work process is often challenged.

2.6.4. Co-Alignment Theory

In highly complex systems such as construction mega-projects, it is very difficult, if not impossible to identify and understands which variables (e.g.: materials, labour and capital cost) that are the direct causes of the managerial problems causing budget overruns and late deliveries. Hence, the level of dynamic relationship and uncertainty during construction mega-projects are foreseen in the literature by two theories (Chandler *et al*., 2014): a) the Co-Alignment Theory and b) the Contingency Theory.

The effectiveness of adaptive response is dependent on aligning the response to the environmental context faced by the organisation (Strandholm *et al*., 2004). The focus of managerial decision-making is on gathering correct information about changes in the environment and examining the consequences of alternative responses because strategic choice among contingencies are more consequential (Astley *et al*., 1983). By nature, construction stakeholders will always face uncertainty during mega-projects, and managers who respond appropriately with the right fit at the right time, are likely to achieve superior performance. Therefore, project managers should abandon the search for universally appropriate strategies in how to manage mega-projects.

In accordance with Chandler *et al*. (2014), the Co-Alignment Theory suggests that the ability of an organisation to adapt to its changing environmental contingencies is to "fit" itself within the operating context. Similarly, specific organisation cultures (construction stakeholders) and leadership styles from directors and managers, have to fit the given environment they are working in. The Co-Alignment Theory (of the Fit) correlated with the Dynamic Capability approach which is based on competitive survival rather than achieving of sustainable competitive advantage sought in the Resources-Based View. Furthermore, the Co-Alignment Theory (of the Fit) is in line with today's construction job sites where changing environment are commonality. Hence, strategic fit if obtained, would enables a construction organisation to operate at peak effectiveness in its competitive situation (Chorn, 1991). However, even though this organisational fit is easy to understand, and indeed, makes common sense, however, the difficulty comes in trying to measure it.

Essentially, according to Chorn (1991), the strategic fit considers the degree of alignment that exists between competitive situation, strategy, organisation culture and leadership. In addition, Chorn (1991) stated in order for an organisation to achieve alignment or fitting, it must be optimised when the appropriate combination of four (4) logics set (production, administration, development and integration) are replicated with four (4) elements (competitive situation, strategy, organisation culture and leadership). The four (4) logics are presented in Table 2.1. Furthermore, each of these four (4) logics are broken down into different types of competitive situation (Table 2.2), business strategies (Table 2.3), leadership styles (Table 2.4) and organisational culture (Table 2.5).

Table 2. 1
Four Logics of the Co-Alignment Theory

Logic	*Means*	*Outputs*	*Associated Phenomena*
"Production" (P)	Action	Results	Objectives, goals, energy
"Administration" (A)	Control	Order	Systems, measurements, stability
"Development" (D)	Create	Change	Innovation, new, discontinuing
"Integration" (I)	Integrate	Cohesion	Synergy, teamwork, co-operation

Chorn (1991)

Table 2. 2
Competitive Situations with the Co-Alignment Theory

	Forgiving	*Turbulent*	*Repetitive*	*Predictable*
Conditions:	High uncertainty, low competitive intensity, low risk	High uncertainty, high competitive intensity, high risk	Low uncertainty, low competitive intensity, low risk	Low uncertainty, high competitive intensity, high risk
Products/Markets:	Augmented products/protected markets. People-based, intangible action	Customised products/novel markets. People-based tangible action	"Commodity" products/mature markets. Equipment-based, tangible action	Differentiated products/growing markets. Equipment-based, intangible action
Customers:	Little knowledge, very involved in delivery	Very knowledgeable, and involved delivery	Little knowledge or involvement in delivery	Very knowledgeable, not involved in delivery
Relationship type:	Continuous delivery, membership	Discrete transactions, intense relationships	Discrete transactions, arm's length relationships	Continuous delivery, arm's length relationships
Structure:	Changing simultaneous customer/supplier		"Fixed" supplier-dominant development	Changing interactive customer/supplier development

Chorn (1991)

Table 2. 3
Business Strategies in Co-Alignment Theory

	Protectionist	*Pathfinder*	*Evolutionary*	*Operational*
Product-Market:	Limited, "value-added" product-line. Relatively stable market — sensitive to value. Growth through extra value-added services	Broad, changing product line. Changing markets. Growth through product development and market development	Limited, stable product line. Stable markets. Growth through market penetration	Predictable and changing product line. Predictable and changing markets. Growth mostly through market development
Research and development:	Mainly in area of "core technology". Emphasis on better product/service to market"	Extensive R&D emphasis on "first to market"	Limited to mostly product development	Focused and practical. Emphasis on "second to market" and "getting it right"
Production:	Low volume-high value added. Emphasis on improving the technology and delivery	Customisation and prototypes. Emphasis on effectiveness and unique product design	High volume - low cost. Emphasis on efficiency and process engineering	High volume - low cost. Some prototypes
Marketing:	Emphasis on value added and improving the quality. People KSF	Emphasis on creative, "problem-solving" research and innovative designs. Product KSF	Limited mostly to increased "sales" efforts. Price KSF	Emphasis on niche effectiveness. Distribution KSF
Distinctive competences:	Emphasis on "quality". Ability to develop long-term, dependent customer relationships	Emphasis on "broad" approach. Spontaneity, ability to anticipate and exceed customer expectations, flexibility	Emphasis on "deep" approach. Efficient, ability to provide customers with value for money, security	Emphasis on "deep and focused", high-energy approach. Reliability, accuracy, responsive to customer needs

KSF = Key Success Factor

Chorn (1991)

Table 2. 4
Leadership Styles in the Co-Alignment Theory

	Revitalisers	*Creators and builders*	*Productivity managers*	*Building and growth managers*
Shared values:	Participation, cohesion, change	Creativity, innovation, rapid response	Control, analysis	Objectivity, facts, results
Team style:	Sensitive to people, offer emotional support — have the ability to empower subordinates	Move very quickly, apparently haphazard — guided by shared vision	Logical, analytical, provide clear structure for their subordinates	Drivers, set clear objectives for their subordinates
Individual aptitudes:	Consensus building, good negotiation skills, good conceptual ability	Individualism, vision, flexibility, tolerance for ambiguity	Good analytical skills, logical, desire for stability	High energy, clear focus on objectives, desire for clarity
Individual knowledge:	Group dynamics, communications	Technical,	Accounting, production	Marketing, sales
Conditions:	Stable, traditional, or about to change	Turbulent, uncertain, rapidly changing	Established, mature, margins under pressure	Settled down, highly competitive
Strategy:	Developing long term relations with customers, or about to change strategic direction	Creation of a market, new product development	Consolidation, fine tuning, improving profits, productivity	Gaining market share, customer focus
Life cycle stage:	Maturity → revitalisation	Gestation → start-up	Maturity	Start-up → growth

Chorn (1991)

Table 2. 5
Organisational Context and Culture of the Co-Alignment Theory

	Group	*Entrepreneurial*	*Hierarchical*	*Rational*
	Organisation as a microcosm of, in harmony with, its environment	*Organisation as societal leader, role model*	*Organisation as guardian of society's assets and knowledge*	*Organisation must fight for survival in a hostile environment*
Values:	Loyalty, commitment, teamwork	Individualism, creativity, flexibility	Analysis, systems, control	Action, objectives, results
Structures:	Divisional, by way of project teams or product/market	Divisional, either product based or market based	Functional	Predominantly functional and matrix
Control process:	Decentralised, predominantly by way of consensus, participation and teamwork	Decentralised, predominantly by way of a shared vision of philosophy	Centralised, by way of explicit rules and regulations	Mostly centralised, by way of clear sets of operating and decision guidelines and principles
Dominant coalition:	CEO, human resources, research and development	CEO, product research and development, market research	CEO, production, finance and accounting	CEO, marketing, process engineering, sales, operations
Culture:	Emphasis on cohesion, teamwork, synergy and consensus	Emphasis on individualism, creativity, fast response	Emphasis on order, stability, information and control	Emphasis on analysis, guidelines and sustained, high levels of activity
	• Closed informal communication which is shared by way of cliques and membership of an "inner circle" • Control achieved by commitment to common values • Management support emphasises the *internal* climate and environment • Individual's tasks are negotiated by consensus • Rewards are based on informal standards and the ability to maintain internal cohesion — good team players	• Open, informal communication which is shared with whoever happens to be around at the time • Control achieved by commitment to a common vision • Management support emphasises leading and inspiring • Individuals are empowered to perform their roles • Rewards are based on creativity and entrepreneurial behaviour • Deviant behaviour is tolerated — provided it is goal directed	• Closed, formal communication which is shared on a "need to know" basis • Control achieved by focus on processes • Management support emphasises procedures • Individual's tasks are established by precedence	• Open, formal communication by way of committees and memoranda • Control achieved by focus on results • Management support emphasises planning • Individuals are given structural authority to perform their roles • Rewards are based on formal standards and relevant results. No deviation from plans or performance standards

Chorn (1991)

Chorn (1991) concluded that organisations both create and respond to their competitive situations, and both should not be viewed as separate, interdependent entities but as just different influences in the same global environment. In addition, Chorn (1991) states the following points on the Co-Alignment Theory:

- Strategic fit is an ideal state which should be continually strived but is rarely achieved. This infinite statement is also in line with the Dynamic Capability approach which strive for continuous competitive survival. Fit is therefore somewhat elusive, but in line with the continuous improvement approach. Within the same philosophy, a construction mega-project will never achieve optimum strategic fit amongst its stakeholders, however, it will seek continuous improvement throughout the project;

- Achieving strategic fit, now or in the future, is the primary task of management;

- They are occasions where management might deliberately cause misalignment in the short term in order to produce increase alignment in the future. This can be seen in construction in promoting disruptive management, such as tracking labour movement, which goes against employee right of privacy but provide owners' justification with safety;

- Owners, Construction Management Teams and contractors will react to changing environment and attempt to reach a strategic fit with a deterministic approach, by shifting the best strategy and culture and/or modifying their leadership style for a specific situation;

- Misalignment of the four (4) elements (competitive situation, strategy, organisation culture and leadership), though, if maintained, is generally associated with a decrease in performance or productivity.

The Co-Alignment Theory of the Fit works well in construction especially where for instance, owners and contractors in the Oil & Gas industries don't have the same building processes as the ones in mining, highways or building. The proposed design in this thesis (CPPM), which will be discussed in Chapter Three and Four, understands the need to fit to a project with general attributes and metrics pertaining to a unique project.

2.6.5. Contingency Theory

Similarly to the Co-Alignment Theory, the Contingency Theory suggests that construction managers play an active role, but somewhat limited, in the continuous process of adapting to the emerging contingencies (Grandori, 1984). The Contingency Theory is a behavioural theory that sees the optimal course of action is contingent (dependent) upon both internal and external situations. In other words, contingency theory claims that there is no standard way to take decision, whereas management decisions are influenced by various aspect of the environment known as contingency factors.

This contingent philosophy is in line with projects whom are seen by the construction industry as being unique in themselves and should be treated and analysed independently. Hence, decision making during mega-projects are contingence to the internal and external environment and an attempt to fit with them.

Thus, in the emergence of mega-project complexities, the contingency views move away from the single and universally applicable model and borrow the path which views that different organisational structures are relevant in different situations (Osteraker, 1999). The four (4) important views of the Contingency Theory are:

1. There are no universal or one best way to manage a project. The type of management style depends on the kind of task or environmental situations one is dealing with. This statement is in line with managing mega-projects where projects and construction managers must adapt their styles of managing, measuring performance and productivity from project to project;

2. Organisations are opened systems that need careful management to satisfy and balance internal needs and to adapt to environmental situations. This statement is true for construction environment, where owners, construction management firms, engineering firms, contractors and union halls, all with diverging objectives as stated in the constructs of this research;

3. The design of an organisation and its subsystems must fit with the environment, like the Co-Alignment Theory of the Fit. Effective organisations not only have a proper fit with the environment but also between subsystems;

4. The needs of an organisation are better satisfied, when it is properly designed, and the management style is in sync with both to the tasks undertaken and the nature of the work group. This statement is in line with the dynamic nature of a mega-project.

2.6.6. Structuration Theory of Duality

The Structuration Theory was proposed by Giddens (1984) and is a social theory of the creation and reproduction of social systems that is based in the analysis of both structure and agents, without giving primacy to either. Giddens (1984) used concepts from social theories that were either objectivist or subjectivist. Favoring duality recognise objectivism which lacked regard for humanist elements and subjectivism's exclusive attention to individual or group agency without consideration for socio-structural context (McLennan, 2001).

Hence, the Structuration Theory of Duality cannot be expected to furnish the moral guarantees that critical theorists or positivists wish to obtain by proving or disproving theories. Construction job sites, especially the ones involved in mega-projects are social systems which have patterns that change over time. The changing nature of space and time determine the interaction of social relations and therefore structure. Therefore, a social system such as a construction site can be studied beyond the realm of human control with a positivistic approach, or by the social action and analysed with a subjective (interpretivist) approach.

Moreover, the duality of structure emphasizes that they are different sides to the same central question of how social order is created (McLennan, 2001). In the case of social system like a construction job site, the process of the duality of structure and agency, stated in the Structuration Theory of Duality, use and produce social actions positively and subjectively.

In the Structuration Theory of Duality, Giddens (1984) focus on providing an abstract ontology (e.g. science of being or reality) accompanied by a broad epistemology (e.g. concern with knowledge through a design) and research methodology that is also broadly detailed. In this way, the Structuration Theory of Duality doesn't prioritize ontology over epistemology. The Structuration Theory of Duality was adapted by researchers interested in the relationship between technology and social structures, such as the use of management information technologies during mega-project.

Giddens (1984) intended his theory to be abstract and theoretical, informing the hermeneutic aspects of research rather than guiding practice. According to Stones (2005), the Structuration Theory of Duality has an internal logical coherence of concepts within a theoretical network. The Structuration Theory of Duality has also allowed researchers to focus on any structure or concept individually or in combination.

Further on in time Desanctis *et al.* (1994) proposed an "adaptive structuration theory" with respect to the emergence and use of group decision support systems (e.g. ERP systems). Desanctis *et al.* (1994) chose Giddens' notion of modalities to consider how technology is used with respect to its spirit. In this adapted Structuration Theory, Sosnoski (1993) used the term "appropriation" which reveal deeper structuration processes and are enacted with action. The term appropriation is defined by Sosnoski (1993) as the assimilation of concepts into a governing framework (Calvin, 2000).

Pavlou *et al.* (2002) argued that research on business-to-business e-commerce portrayed technologies as overly deterministic. The authors employed structuration theory to re-examine outcomes such as trust, coordination, innovation, and shared knowledge. Pavlou *et al.* (2002) looked beyond technology, but more into organizational structure and practices, and examined the effects on the adapting structure to new technologies when implemented.

Following the Structuration Theory of Duality and the construct of theoretical incapacity, the researcher went on to explore the final research methodology: Design-Science Research (DSR). Details of the DSR are found in Chapter Three. In general, DSR, is similar to the Structuration Theory of Duality, which was similar to the Co-Alignment Theory and the Contingency Theory, which were also in line with the Concept of the Fit.

Like the other theories above, DSR recognizes the theoretical incapacity, thus doesn’t aim at analyzing a construction phenomenon, a law nor a theory per se. Instead, the objectives of DSR are to show factual characteristics, in order to be able to identify causal relations. This is why the design proposed in this research (e.g. CPPM) was obtained from the basic framework of the Design-Science Research as being a very practical "know-how" that cannot be relegated down to an attempt to provide theory (Baskerville *et al.,* 2015).

2.7. CURRENT RESEARCH TRENDS IN CONSTRUCTION MANAGEMENT LITERATURES

Many authors argue that construction industry could benefit from greater attention to supply chain management (Agarwal *et al*., 2016; Akintoye *et al.*, 2000; Changali *et al*., 2005; Cox *et al*., 2002; Thunberg *et al.*, 2014; Vrijhoef *et al*., 2000). In general, supply-chain researches will tend to emphasis on issues that affect managing networks and the benefits of supply chain integration (Gulledge *et al*., 2008). While there are extensive amount of construction literatures related to supply chain management, lots of them focus on: a) tracking materials and equipment leaving suppliers and their explicit arrival to sites, b) their subsequent effects on the project performance, such as delays and missing materials, and c) mathematical modeling.

Several studies focused on improving supply chain design quantitatively with advanced mathematical models, of which construction stakeholders don't know how to apply. Then, there are the ones that are economy focus researches, which target the assessment of contractors' performance and productivity against financial KPI. However, the researcher did not find in the current literatures, studies measuring the level of supply chain processes during engineering (concept, front end and detailed) and construction phases.

2.7.1. Strengths in Construction Literatures

The financial and operational objectives of an integrated supply chain are to reduce operational costs and increased revenues through differentiating their products or services, and subsequently adding internal values (Matta *et al*., 1995). These supply chain objectives correlate with most literatures regarding the same reasons why organisations should adopt information technologies during construction mega-projects.

In search of competitive advantages, studies in construction management with supply chain approaches, have targeted the ability on adding economic value to an organisation by either reducing operational costs such as tracking materials at construction sites, or differentiating its products or services like offering RFID cards to employees for safety reasons (Akinci *et al*., 2006; Angeles, 2005; Chae *et al*., 2010; Ergen *et al*., 2011; Lin, 2008; Matta *et al*., 1995; Matta *et al*., 2009; Srivastava, 2004).

Literatures related to geo-decisional systems such as GPS, RFID, RTLS and WMS are abundant with detailed assessment of costs and time benefits. These studies are well documented on what benefits these geo-decisional systems provide the end-users. For instances, researchers have shown findings on improving accuracies and providing timeless data (Akinci *et al*., 2006, Chae *et al*., 2010; Ergen *et al*., 2011). In addition, studies where geographical information systems (GIS) were used in construction, they provided more accurate inventories, minimised routing, and improved production and performances, due primarily to less time wasted by crews whom were looking for materials and equipment (Akinci *et al*., 2006, Chae *et al*., 2010; Ergen *et al*., 2011). In general, these geo-decisional tracking systems will provide accurate inventories, minimise routing of the goods and routing of crews in search of materials and equipment.

Overall, geo-decisional tracking systems will improve overwhelmingly the material management processes at any construction sites (Chan *et al*., 2009; Shipton *et al*., 2014). Other authors (Akinci *et al*., 2006; Angeles, 2005; Chae *et al*., 2010; Ergen et al., 2011; Lin, 2008; Matta *et al*., 1995; Matta *et al*., 2009; Srivastava, 2004) in construction management literatures have often attempted to find a solution to the managerial problems (e.g. projects being completed over budget and late in schedule delivery) by using mathematical simulations, advanced algorithm and complicated formula that are unfriendly to construction management staffs and not viable in a construction environment. These quantitative improvements tend to lean on the objectivity of positivism and rationalism, in line with natural science (Shipton *et al*., 2014; Wing et al., 1998). Although modeling can be useful in understanding specific problem, they do little to assist management at construction site in controlling human behavior, reducing the burden of overrun costs and delays during mega-projects.

Furthermore, the researcher did not come across one literature that examine or measure the robustness level of operating a true end-to-end supply chain process, throughout all phases of construction project management. In fact, to gain insights on how many supply chain processes are in place during mega-projects, researchers must understand the interactions between various projects' stakeholders, their activities across all project phases, analyze and measure the level of processes that are in place. The researcher believes there is no point of integrating processes, if they are not going to be measured throughout the construction phases. Chapter Four – section 4.1 Project Flows will demonstrate the observed project activities, of which the researcher was able to record from its participant observation methodology.

2.7.2. Gaps in Construction Literatures

On one side of the academia, the current literature in construction management, as described in the previous section, tends focus on tracking the flow of materials from leaving suppliers' properties, to the arrival of materials and equipment at construction sites. Meanwhile, on the other side, other schools of research offer mathematical modeling, which, in accordance to the researcher, tend to lean on resolving micro-problems. Interestingly, construction sites are far from being consider as micro-environment. Other literatures use individual perceptions (surveys and interviews) or artificial methods (simulation and mathematical modeling) for research in construction (Palsson, 2007).

Evidently, construction mega-projects are more than just being an empirical or rational testing laboratory. It also involves hundreds or thousands of workers and staffs, which must be drawn objectively like in social science. Hence, the researcher believes that relativism, constructivism and subjectivism of the social science are as important as rationalism, positivism and the objectivity of the natural science.

Some of the literatures in construction management also discuss the importance of innovation as a mean of improving productivity but it does not sufficiently describe mechanisms through which innovation can be embedded into the construction industry operating culture (Maqsood *et al*., 2009).

Evidently, literatures in manufacturing, which consider the measurement of the supply chain processes from end-to-end, are beyond abundant. There are overwhelming thousands of studies in many languages and countries. Unmistakably, literatures in construction's supply chain management, are practically inexistent. In fact, the researcher did not come across studies in construction management, like the manufacturing sectors, which consider the following integration benefits:

1. The wide benefits of information technologies and their strategic effects across end-to-end supply chain (Fosso Wamba, 2009);

2. The value of integrated Vendor Replenishment Planning systems with multiple supply chain participants (Fosso Wamba *et al*., 2009; Li *et al*., 2006; Ngai *et al.* 2008, Ranasimghe *et al*., 2004);

3. The level of supply chain's integration processes in construction project management, and which attributes and metrics are essential to measure the level of performance and productivity during mega-project?

The detailed engineering and the construction phases are by far the one that provides the most data information throughout the project lifecycle, however, there is limited information and knowledge on process integration between these two (2) phases. The researcher believes there are many reasons for lack of literature. For instance:

- Limited accessibility for researchers to take active part in live the site experience during construction projects;

- Cultural and technological clashes between construction stakeholders and academic researchers;

- Technological lagging related to management information systems throughout the construction industry;

- Organizational divergence between stakeholders' goals and objectives;

- Unwillingness to transfer or share data between stakeholders;

- No standardization in progress reporting, hence making comparison hard to identify;

- Controlling the uncertainties during the construction phase remains an enigma;

- There is a gap in observing operational process against performance and productivity measurement during the construction phase, and their correlated impact on the overall project success.

Therefore, the researcher believes there is a need to capture the entirety of the supply chain processes during construction mega-projects, of which informal and emergent performance attributes and KPIs metrics co-exist. In retrospect, this thesis found the following gaps in literatures:

- There seems to be no or little studies, which discuss the root causes of process changes expected to appear, when introducing information technologies at construction sites;

- Construction management studies also demonstrate the importance of innovation as a means of improving productivity. However, the construction literatures don't sufficiently describe mechanisms through which innovation can be embedded into the operating processes (Maqsood *et al*., 2009);

- In today's current literatures, there is no holistic or near-holistic model, nor any solid-proof framework, which measures performance and productivity through attributes that pertain to the construction environment, which start at the conceptual phase of a project, followed through by the front-end planning and detailed engineering phases, and finally, ending at the construction and commissioning phases;

- To know whether the supply chain processes are being effectively implemented or not during construction mega-projects, one must measure the end-to-end supply chain, from concept, to front-end planning and detailed engineering and especially during the construction phase. As far as the researcher is concerned, there are no studies demonstrating such results;

- According with Chan *et al*. (2014), there exists no structural framework for implementing supply chain management in a construction environment. A supply chain framework must be adapted to construction characteristics, to be used for mapping and measuring performance and productivity.

Akyuz *et al.* (2010), (1999) Erkan (2010) and Beamon (1999) conducted comprehensive reviews of supply chain models and concluded that the current literatures suffered from the following limitations:

- Models in literatures focus on cost as the primary measure of performance;
- Models relying on cost measurement are insufficient and could be potentially misleading;
- Models rely on single, mainly economical-oriented, supply chain performance measurement;
- Models ignore the interactions among different stakeholders' strategies;
- Models ignore the potential influence of uncertainty which are outside management controlled, but have a strong influence on supply chain performance;
- Models ought to reflect duality and multiplicity of goals and outcomes, and they should include quantitative and qualitative measures;
- Measurements should consider the effect of their environment or situation-related factors;
- Measurements should be compared against the best possible potential performance (KPI) related to construction.

2.7.3. SCOR Model's Processes

Literatures and technical journals offer several approaches that can "partially" solve the managerial problematic of this thesis. For instance, in Reinventing Construction: A Route to Higher Productivity, McKinsey & Co. (2017), proposed seven (7) areas that could boot construction productivity by 50% to 60%. These seven (7) elements which could improve construction productivity are as followed:

1. Reshape regulations;
2. Rewire contracts;
3. Rethink design through modular construction;
4. Improve procurement and supply chain;
5. Improve onsite execution, using data analytics;
6. Infuse technology and innovation, with intelligent tablets;
7. Reskill workers.

For the purpose of this thesis, the route to implementing supply chain processes into construction sites is presented as one potential element to improve construction productivity. The researcher believes that a properly designed performance measurement system, is the cornerstone for effective coordination, control and enhanced results. Thus, the growing attention to supply chain performance in construction should be measured and analyzed (Gunasekaran *et al*., 2004).

Since there exists no structural framework for implementing supply chain processes in a construction environment, such a framework would have to be adapted to construction characteristics, to be used for mapping and measuring performance and productivity. Introducing a supply chain framework, as the base model to control cost, schedule and quality would be disruptive to the construction culture. But, the necessity for a change or disrupt in how construction projects are managed, have been stressed by many authors (Ballard, 2010; Karim *et al.,* 2006, Latham, 1994; Egan, 1998).

In view of the gaps in literatures having a model or a framework, which would cover all activities of construction project management, and in view of McKinsey & Co. (2017)'s fourth proposal "*Improve procurement and supply chain*", this research reviewed the SCOR (Supply Chain Operations Reference) Model as the basic framework for this thesis. The SCOR Model will be eventually enriched, then simplified into a “easy to use” model by construction stakeholders.

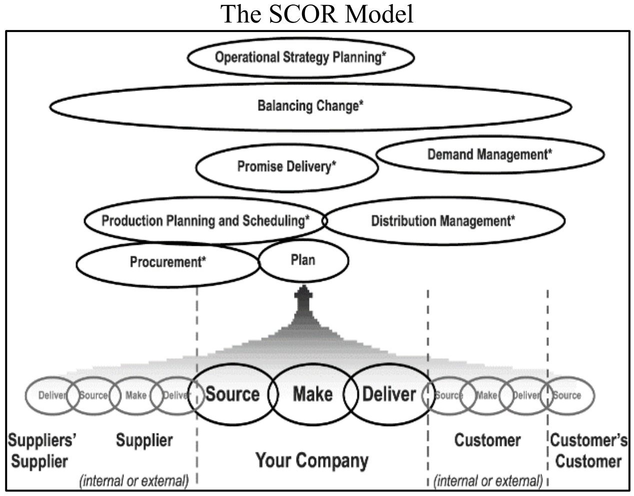
In summary, the SCOR Model has been created by the Supply Chain Council for the manufacturing sectors and is one of the best options for measuring end-to-end processes in construction projects. This model is constantly optimised by thousands of manufacturers’ participants taking part in providing warehousing data. The SCOR Model is a powerful tool to measure manufacturing’ supply chain performance.

However, many authors such as Cheng *et al*. (2010); Gunasekaran *et al*. (2004) and Johansson *et al*. (2011) have argued the SCOR Model, by itself, has to be adapted to better embrace the characteristics of the construction industry.

2.7.3.1. SCOR Framework

The SCOR framework combines elements of business process engineering, metrics, industries’ benchmarking, leading practises and people skills into a single framework (Bolstorff et al., 2012). Under the SCOR Model, supply chain management are defined as several integrated processes including of Plan, Source, Make, Deliver and Return. Figure 2.23 demonstrate the business processes of the SCOR Model.

Figure 2. 23
The SCOR Model



Supply Chain Council (2018)

2.7.3.2. SCOR Model's First Process: Planning

In the SCOR planning process, a manager will assess its supply resources, priorities demand requirement, plan inventory for distribution, production and material requirement, and plan a final rough-cut capacity for all materials and all network channels. The procurement processes (materials and equipment) between suppliers, buyers (EPC, EPCM, CMT) and project owners during mega-projects are identical to the manufacturing ones.

The SCOR Model is an excellent tool for measuring the procurement process during the planning process of a construction project. For instance, some of the construction planning activities are similar to the SCOR's manufacturing sectors. In addition, title functionalities may not be the same between construction and manufacturing, however, their roles in both industries have similar activities. For instance:

- Conceptual Phase: management must establish preliminary budgets and conceptual estimates complemented with a risk-management plan that will anticipate market changes;

- Planning Phase (Front-End and Detailed Engineering phases): management must define and outline scheduling and logistics key components;

- Planning Phase: management must commit to a constructability review to ensure the most efficient and economical way of building the project, while applying the construction knowledge into the front-end planning and detailed engineering phases;

- Planning Phase: package dictionaries are coordinated between engineering and construction department in preparation of installation work packages (IWP);

- Document Control Lead are responsible during planning phase (and construction) for setting up and managing the flows of informal communication for the project, filing and archiving of documents, establishing for version control;

- Contract Lead are responsible during the detailed engineering phase (and construction) for developing and implementing the project delivery methods, establishing contractual approaches with contractors and suppliers, and develop contract language and enforcing contractual terms during the construction execution;

- Cost Control Lead are responsible during all phases of any project, to set up and track the project finance, to establish accounting codes and to set up the cost reporting system, during the construction and commissioning phases;

- Estimators are responsible for developing and estimating the project cost during the planning phase (front-end and detailed engineering phases) and manage the construction change management system during construction (production for manufacturing);

- Planners will develop, during the planning phase (front-end and detailed engineering phases) work forecast and ensure that all elements of works are planned ahead, including manpower, materials, equipment, safety requirement and quality plans. During the construction phase (production for manufacturing), planners will liaise with contractors to oversee the workforce planning effort, including preparation and execution of Field Installation Work Packages;

- Schedulers are responsible for assemblies and maintaining the overall project schedule and increasing the level of scheduling as the design evolves throughout the project phases;

- Procurement staffs are responsible, throughout the project, for purchasing, procuring and expediting materials and equipment, logistics to sites (or manufacturing plants). For the construction part, a material lead would take over the procurement responsibilities and commit to materials management activities such as receiving, warehousing and pick & pack before installation.

2.7.3.3. SCOR Model's Second Process: Source

The sourcing activities in SCOR include the physical movement of materials, equipment and other freights. Sourcing also deals with the reception of materials, their inspections, shortages, back-orders, damages or failed equipment. The SCOR Model is an excellent tool for measuring the procurement processes during the sourcing phase. Similar functions between manufacturers and engineering/construction are executed by the procurement team, including buyers, expediting, transport & logistics and site materials located at a construction site.

In a construction project, a procurement department will attempt to deliver the correct product to the correct place, at the correct time, in the correct condition and packaging, with the correct quantity and documentation, and finally to the correct customers. During the sourcing process, a construction stakeholder will seek the reliability to perform tasks as expected and on the predictability of the outcome of a process. For instance, some of the construction activities are like the SCOR's manufacturing sectors, and are as followed:

- Sourcing and prequalification of potential suppliers;
- Preparation and issuance of Purchase Orders and construction contracts;
- Coordination with planning and construction to ensure schedules and any changes reflect project requirements;
- Preparation of request for quotations and tenders, bid evaluations and award recommendations for equipment, materials, services and construction contracts;
- Plan and ensure efficient and timely follow-up of suppliers during the fabrication cycle;
- Use of international services and providers to monitor manufacturers, for expediting and quality surveillance activities;
- Evaluation, implementation and execution for optimized logistics solutions based on geographical locations and other project requirements;
- Optimizing inventory management;
- Pick and pack in accordance with field installation schedule.

2.7.3.4. SCOR Model's Third Process: Make

The Make Process in the SCOR Model must to be adapted to reflect the activities of construction mega-projects. In the current statements of the SCOR activities, they include the making of products, conducting their factory tests, packaging and releasing them as end-products for eventual customers.

Overall, the Make process in the manufacturing sectors are more incline in understanding the upside and downside flows of their integrated supply chain. The Make process in manufacturing is more of a sterile place and operate in a quasiimmune environment from external influences. The researcher, therefore, states the SCOR Make Process, as presented by the Supply Chain Council, only applies to the manufacturing sectors and cannot be utilised in the construction industry. The SCOR process doesn't have the abilities to respond to construction changes.

In such, this Make process is changed under the proposed DSR's artifact, which is detailed in Chapter Four – Result. Hence, the Make process, as presented in the DSR artifact, measures attributes and performance metrics belonging to four (4) major departments: (1) engineering, (2) procurement, (3) construction management, (4) project cost controls, (5) workers management, (6) complexity and (7) integration. In addition, the DSR's Make process has the ability, flexibility and adaptability to respond to external and internal influences, the ability to respond to changes, to maintain or to improve the project's scope objectives (deliver on time, on budget and at the highest quality). Hence, the SCOR Make process during the construction phase is in sort, design to take for account the needs of all stakeholders participating in mega-projects.

Construction stakeholders hold various functional activities during mega-projects. For instance, the Make process for the construction industries have the following functionalities:

- Document Control Lead, Contract Lead, Cost Control Lead, Estimating, Planning, Scheduling and Procurement / Material Lead;

- Field Coordinators: are responsible for continuous liaison with crews and field supervision to address issues as they arise in the field. They also monitor progress and productivity, inspection, and coordination with other roles on the construction management team to ensure that any bottlenecks affecting works are identified and addressed;

- Field Engineers: act as the link between the design team and the construction team and monitor the works that are being performed in accordance with the scope of works, drawings and specifications. Field Engineers also address contractors' requests for information, technical clarification, supplementary instructions or scopes of works from the field;

- Quantity Surveyors: are responsible for quantifying works in the field and to validate progress payment for the work and accurately assess remaining work effort;

- Quality Control Lead: are responsible for setting up and managing the construction quality program, including inspection and test plans, identification and resolution of non-conformances, management of concessions, identification and implementation of corrective or preventive actions, review of contractors' quality programs and documentation. Quality Control Leads also interface with authorities having jurisdiction to ensure that works are performed in accordance with regulatory or statutory requirements;

- Safety Leads: will ensure that safety processes are implemented, monitors and track. They also provide on-site training and orientations, as well as facilitating safe work planning. Safety Leads also perform regular inspections and audits of the contractors' safety programs.

2.7.3.5. SCOR Model's Fourth Process: Deliver

The activities for the Deliver process in the SCOR Model are targeted toward the downside flows of the finishing end-product, including final total costs, which comprises all costs from the planning, sourcing and making processes as well as their related transportation and logistics costs. For instance, the activities of the Deliver Process in manufacturing are:

- Executing order management processes are typical activities in the manufacturing sector;

- Create and maintain customer databases and maintain product/price databases;

- Maintain account receivable and payable, credits, invoicing and collections;

- Execute warehouse processes, including pick and pack;

- Manage transportation and any other logistics requests.

Where the Deliver process in the manufacturing sectors are more concerned with the final downside flow of the end-product and the costs associated with them, the Deliver Process in construction targets the activities of commissioning, care, custody and turnover. Note that while a final product is often delivered to a customer, the construction's final product remains at a site.

At the time of turning over the end-product to the owners, surplus and spare parts are entered into the owner's ERP system, preventive maintenance programs are developed and working instructions are written as required. The Comissioning Team will oversee the effort to start-up the equipment safely, develops the program for testing the equipment, ensure the owners' requirement meet the performance specifications, and assembles final turnover documentations for the owners.

2.7.3.6. SCOR Model's Fifth and last Process: Return

The SCOR's Return Process activities include defectives equipment, warrant, disposition and replacement. Similarly, in construction, any broken machineries, equipment and parts must be replaced. Hence, the Return Process in the manufacturing and construction sectors conduct very similar activities.

In summary, the primary reason for selecting the SCOR Model is based on the business processes which provide a framework for common language and facilitate horizontal integration across different business units (engineering, procurement and construction management) and stakeholders (suppliers, owners, engineers, contractors, consultants, crew trades, etc.).

However, the SCOR Model's process phases, as used in the manufacturing sectors, are partially effective in measuring the activities of construction project management. The SCOR' Planning, Sourcing and Returning processes conduct similar activities in both manufacturing and construction industries. However, the Make and the Deliver processes which the SCOR Model presents, must be adapted to the uniqueness of mega-projects and construction management.

2.7.3.7. SCOR Model's Attributes and Metrics

It is stated above that only the SCOR's Planning, Sourcing and Returning processes have similar activities in construction management. Nevertheless, the researcher decided to re-write the Make and Deliver processes from the original SCOR Model, in order to reflect the engineering and construction activities from conception to turn-over, and the reality of the environment at job sites.

Hence, this section will compare SCOR's attributes and demonstrates why the researcher believes a modified model is required when facing mega-projects' realities. Beyond five (5) processes enumerated in the previous section (Planning, Sourcing, Make, Delivery, Return), the SCOR Model is also made up of seven (7) performance attributes. Each of these attributes are then sub-categorised in three (3) level metrics (Level I, II and III). The SCOR' performance attributes are:

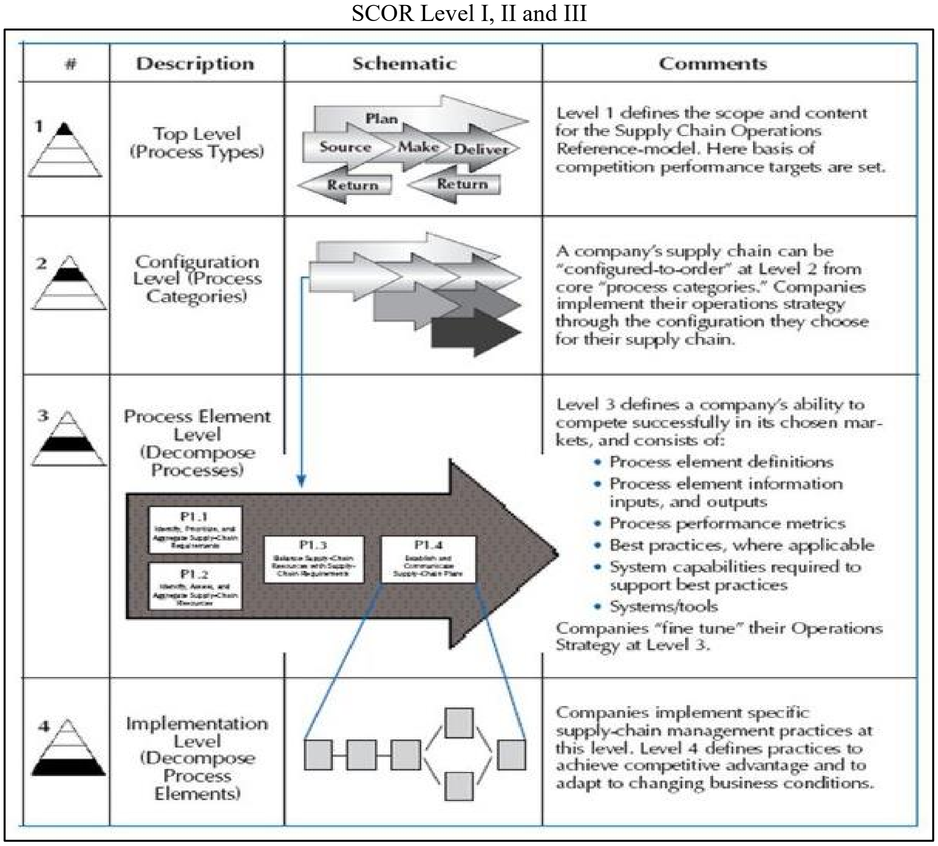
1. Supply Chain Reliability;
2. Supply Chain Responsiveness;
3. Supply Chain Agility;
4. Supply Chain Costs;
5. Supply Chain Assets Management;
6. Supply Chain Complexity;
7. Supply Chain Maturity.

Level I metrics define the scope and content for the SCOR Model, whereas, Level II metrics define the configuration of planning and execution strategies in material flow, using standard categories such as make-to-stock, make-to-order, and engineer-to-order. Companies will implement their operations strategies in Level II.

Level III metrics define the business processes and system functionalities used to transact sales orders, purchase orders, work orders, returned damage items, replenishment orders and forecasts. Level III defines a company's ability to compete successfully in its selected markets. It consists of: a) process element definition, b) process element information inputs and output, c) process performance metrics and d) best practices.

Level IV metrics are not contained in the SCOR Model but must be defined in order to implement improvement and manage processes. Here, companies will implement specific supply chain management practices at this level. For the purpose of this doctoral thesis, Level IV will not be covered. Table 2.6 describes the details of Level I, II and III.

Table 2. 6
SCOR Level I, II and III



#	Description	Schematic	Comments
1	Top Level (Process Types)	Plan, Source, Make, Deliver, Return, Return	Level 1 defines the scope and content for the Supply Chain Operations Reference-model. Here basis of competition performance targets are set.
2	Configuration Level (Process Categories)		A company's supply chain can be "configured-to-order" at Level 2 from core "process categories." Companies implement their operations strategy through the configuration they choose for their supply chain.
3	Process Element Level (Decompose Processes)	P1.1, P1.2, P1.3, P1.4	Level 3 defines a company's ability to compete successfully in its chosen markets, and consists of: • Process element definitions • Process element information inputs, and outputs • Process performance metrics • Best practices, where applicable • System capabilities required to support best practices • Systems/tools Companies "fine tune" their Operations Strategy at Level 3.
4	Implementation Level (Decompose Process Elements)		Companies implement specific supply-chain management practices at this level. Level 4 defines practices to achieve competitive advantage and to adapt to changing business conditions.

Supply Chain Council (2018)

1. Supply Chain Reliability

The first performance attribute is Supply Chain Reliability. It is defined as the performance of an organisation in delivering the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customers. Table 2.7 illustrates the relations between the first attribute of the SCOR Model and its three metric levels.

This attribute is very pertinent in construction management. The metrics utilised in the SCOR Model's Level I, II and III are like the metrics selected in the thesis' artifact, described in Chapter Four. However, to be in line with the engineering and construction taxonomies, the expression Procurement Reliability is used instead of Supply Chain Reliability.

Table 2. 7
Supply Chain Reliability

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
1	Supply Chain Reliablity	The performance of the SC in delivering the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customers.	Delivery Performance & Perfect Order Fulfilment (qty, %)	Scheduled Orders to Customer Request Delivery Performance to Request Date Delivery Performance to Commit Date Perfect Order Fulfillment	Procurement Reliability

Supply Chain Council (2018)

2. Supply Chain Responsiveness

Supply Chain Responsiveness is SCOR's second attribute. It is defined as the speed at which a supply chain provides products to the customers. This is the average actual cycle time consistently achieved to fulfill customer order. Table 2.8 illustrates the relations between the second attribute of the SCOR Model and its metric levels.

This attribute is also pertinent in construction management. The model's Level I, II and III metrics utilise in the SCOR are similar to the metrics selected in the thesis' artifact, which is described in Chapter Four. However, to be in line with the engineering and construction taxonomies, the expression Procurement Responsiveness is used instead of Supply Chain Responsiveness.

Table 2. 8
Supply Chain Responsiveness

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
2	Supply Chain Responsiveness	The speed at which a SC provides products to the customers. This is the average actual cycle time consistently achieved to fulfill customer order.	Order Fulfilment Cycle Time (days)	Customer Signature / Authorisation to Order Receipt Order Receipt to Order Entry Complete Order Entry Complete to Start Pick/Pack of Order Start Pick/Pack of Order to Order Ready-to-Ship Order Ready-to-Ship to Customer Receipt of Order Customer Receipt of Order to Installation Complete	Procurement Responsiveness

Supply Chain Council (2018)

3. Supply Chain Agility

The agility of a supply chain is the third attribute to the SCOR Model. It is defined as the ability to respond to external influences, the ability to respond to marketplace changes in order to gain or maintain competitive advantage. In addition, the metrics for this performance attributes are sub-defined into flexibility and adaptability. The flexibility of a supply chain agility is measured in days, whereas, the adaptability is accounted in percentage. Table 2.9 illustrates the relations between the third attribute of the SCOR Model and its metric levels.

This performance attribute is not pertinent to the construction industry, especially when building mega-projects. In construction, trying to understand the upside and downside flows of each piece of materials and equipment that are to be installed is not sought during a project. Furthermore, this type of activity-based-costs (ABC) in the manufacturing sector is easier to achieve due to the level of automation and production prediction. Hence, the researcher chose to replace the taxonomy of supply chain agility in SCOR by the expression EPCM Agility, as it is described in the thesis' artifact, found in Chapter Four.

Table 2. 9
Supply Chain Agility

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
3	Supply Chain Agility	The ability to respond to external influences, the ability to respond to marketplace changes to gain or maintain competitive advantage. The metrics for SC Agiliy include Flexibility (days) and Adaptability (%) .	Upside SC Flexibility (days)	Upside Supply Chain Flexibiity Upside Suply Chain Flexibility	EPCM Agility
			Upside SC Adapatability (%)	Upside Supply Chain Adaptability Upside Suply Chain Adaptability	
			Downside SC Flexibility (days)	Downside Supply Chain Flexibility	
			Downside SC Adaptability (%)	Downside Supply Chain Adapatability	

Supply Chain Council (2018)

4. Supply Chain Costs

The supply chain costs are SCOR's fourth attribute. It is defined as the cost associated with operating a supply chain network. The supply chain costs include the total cost to serve from one end to the other end. Table 2.10 illustrates the relations between the fourth attribute of the SCOR Model and its metric levels.

This attribute is pertinent to construction management in a sense that project costing account not for the supply chain costs, but for all four (4) functionalities of a mega-project, which are procurement costs, engineering costs, construction and management costs, as well as labour costs. Therefore, the Level I, II and III metrics utilised in the SCOR Model are like the ones in a construction environment. To be in line with the engineering and construction taxonomies, the expression Project Controls is used in the thesis' artifact, as it is described in Chapter Four.

Table 2. 10
Supply Chain Costs

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
4	Supply Chain Costs	The cost associated with operating the SC. This is the total cost to serve.	Total Costs to Serve	Order Management Cost Material Acquisition Cost Inventory Carrying Cost Supply Chain Related Finance, Planning & IT Costs	Project Controls

Supply Chain Council (2018)

5. Supply Chain Assets Management

The supply chain assets management is the fifth attribute related to the SCOR Model. It is defined as the effectiveness of an organisation in managing assets to support demand satisfaction. This include the management of all assets: fixed and working capital. Table 2.11 illustrates the relations between the fifth attribute of the SCOR Model and its metric levels.

This attribute is not pertinent to a construction management team, especially when building mega-projects. Construction stakeholders which are involved in the execution phase are more concerned with the performance and productivity of crews, rather than cash-to-cash cycle time, return on fixed assets or return on working capital. This accounting type attribute is more important at a corporate level than into a construction field.

For this attribute, the researcher believes that measuring crews and management performance is more important than measuring cost of holding inventories, days of sales outstanding, etc. Hence, the researcher replaces the attribute of supply chain assets management in SCOR by the expression Workers (Assets) Management, as it is described in the thesis' artifact, found in Chapter Four.

Table 2. 11
Supply Chain Assets Management

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
5	Supply Chain Assets Management	The effectiveness of an organisation in managing assets to support demand satisfaction. This include the management of all assets: fixed and working capital.	Cash-to-Cash Cycle Time	Inventory Days of Supply Raw Materials Inventory Days of Supply WIP Materials Inventory Days of Supply Finished Goods	Workers (Asset) Management
			Return on SC Fixed Assets	Inventory Days of Supply - Finished Good Inventory Days of Supply - Raw Materials	
			Return on Working Capital	Days Sales Outstanding Average Payment Period Total Inventory Days of Supply Cash-to-Cash Cycle Time (days)	

Supply Chain Council (2018)

6. Supply Chain Complexity

The sixth attribute of the supply chain is SCOR Model is complexity. The complexity of a supply chain embraces the nature of dealing with local or international manufacturers, the amount of distributions centres to manage, where customers and suppliers are geographically located in relation to the fabricants' plants. High levels of supply chain complexity, left unmanaged, reduce operational performance and certainly leads to higher costs. Table 2.12 illustrates the relations between the sixth attribute of the SCOR Model and its metric levels.

This attribute is very pertinent to procurement and construction management. Projects' complexities include the works executed at construction sites and the procurement and logistics complexities which occur off-construction sites, such as dealing with global suppliers. Therefore, the Level I, II and III metrics used in the SCOR Model will be very similar to the procurement and construction management.

Finally, to be in line with engineering and construction taxonomies, the researcher replaces the attribute of supply chain complexity by the expression Project Complexity, as it is described in the thesis' artifact, found in Chapter Four.

Table 2. 12
Supply Chain Complexity

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
6	Supply Chain Complexity	Complexity is assessed along multiple dimensions. High levels of supply chain complexity, left unmanaged, reduce operational performance and lead to higher costs.	Physical Product Flow	Manufacturing Complexity	Project Complexity
				Distribution and IT Centers Complexity	
				Customer Base Complexity	
				Supplier Base Complexity	
			Process and System in Place	To Manage Sales & Operations Planning	
				To Manage New Product Introduction	
				To Manage Postponement and Configuration Strategy	
			Product & Sales	Number of SKUs Offered	
				Number of Annual Product Introduction	
				Number of Finished Product Item Codes	
				Number of Finished Product Purchased from 3rd Party	
				New Product Introductions	
				End of Life Product Retired During the Year	
				Number of Promotional SKUs	

Supply Chain Council (2018)

7. Supply Chain Maturity

The seventh and final attribute to the SCOR Model is the supply chain maturity. This qualitative assessment evaluates how well an organisation is integrating processes and information systems across an organisation's supply chain. So, the maturity of an organisation's supply chain is a self-assessed measurement. It compares an organisation to a pool of competitors operating in the same industries. Table 2.13 illustrates the relations between all seventh attribute and metric levels.

In the situation of construction project management, the duration of a project doesn't last long enough to be measured in a form of maturity. In fact, the qualitative assessment of maturity in a project has no impact in improving the managerial problems presented in this thesis.

Therefore, the attribute of supply chain maturity is not pertinent to construction management. Instead, the researcher proposes to measure the level of project integration amongst construction stakeholders. For example, the procurement integration between suppliers and owners, or data transparency between owners and contractors, etc. are some examples of project integration.

Finally, to be in line with engineering and construction taxonomies, the researcher replaces the attribute of supply chain maturity in SCOR by the expression Project Integration, as it is described in the thesis' artifact, found in Chapter Four.

Table 2. 13
Supply Chain Maturity

	SCOR MODEL				CPPM
No.	Performance Attribute	Definition	Level 1 Metrics	Level 2 Metrics	Performance Attribute
7	Supply Chain Maturity	The qualitative practice assessment framework evaluates how well your organisation is integrating processes and information systems across your SC.	Self-Assessed Practices	Strategy, Plan, Source, Make, Deliver, Return	Project Integration

Supply Chain Council (2018)

In summary, the researcher reviewed leading journals within the fields of logistics, RFID implementation, supply chain, project and construction management, as well as management information systems and operations management, in both manufacturing and construction settings. The reviews of leading journals in construction management demonstrated a clear breakdown in promoting an end-to-end supply chain processes during mega-projects. Hence, this thesis is prone into integrating supply chain processes into construction project management, as one of many options, which will improve controlling projects' budget and schedule deliveries.

Evidently, mega-projects are more than just being empirical or rational testing laboratories. It also involves hundreds or thousands of workers and staffs which must be drawn objectively like in social science. Finally, this thesis believes that new studies investigating supply chain processes during mega-projects are needed, and future researches must look beyond the current tunnel practices of tracking of materials, equipment and labours or conducting mathematical modelling with little appeal to construction staffs. One reason for lack of constructive approach in construction management literature is caused by the fact that very few scholars have direct access to construction fields. Hence, several scholars when conducting construction studies would rather conduct simulation modeling, which do not often match the advancement of reality world of construction.

Existing reviews of studies also demonstrate that direct observations such as participant observation and action research, which were selected as two methodologies for this thesis (ref: Chapter Three), are rather unpopular in construction management studies. In fact, the author encountered few review studies (Sachan *et al*., 2005, Mentzter *et al*., 1995; Palsson, 2007) that offered participative research methodologies. The apparent lack of participant observation research is also confirmed in a review case study offered by Seuring (2006).

2.8. RESEARCH CONTRIBUTION TO THE CONSTRUCTION INDUSTRY

Overall, studies in manufacturing, which consider the measurement of the supply chain processes from end-to-end, are not abundant. There must be overwhelmingly thousands of studies in supply chain's manufacturing. On the other hand, literatures in construction management, which consider the integration of supply chain processes, especially during the construction phase, are practically inexistent. In fact, the researcher did not come across studies that investigates supply chain processes in construction management.

Consequently, the current literature in construction management has focused on tracking good, meanwhile, on the other hand, several researches offer mathematical modeling which lean on resolving micro-problems, of which construction sites are far from being a micro-environment. There are also some of the literatures in construction management, which discuss the importance of innovation as a mean of improving productivity, but they don't sufficiently describe mechanism through which innovation can be embedded into the construction operating culture (Maqsood *et al*., 2009).

Today, the researcher has noted over the last five to ten years that the Canadian construction industry has reached a breaking point, in a competitive sense, where it is facing increasing global competition in a changing environment, right at home. Trade barriers and protectionism are falling, transaction costs decline, and foreign construction companies can bid and win contracts within the Canadian construction industry.

Similarly, Canadian mining companies have been entering new regions and no longer need to invest in Canada. Thus, the construction industry must immediately shift to accommodate the demanding requirement imposed by global threats and project owners to reduce costs and deliver on-time (Young *et al*., 2011).

Construction organisations must carefully diagnose the nature of their competitive threats and understand their comparative advantages and disadvantages relative to other global players. Developing new and improved services will be important, meanwhile ineffective organisations will be suffering from not attempting to understand their underlying process-driven performance (Changali *et al*., 2005). As a result of more competition and the increased cost of subcontracting and materials, the concept of supply chain management has emerged as a competitive weapon (Benton *et al*., 2010). The needs to use effective BI tools for the purpose of decision-making processes are highly needed in construction (Sangari *et al*., 2015).

2.8.1. Material Errors & Uncontrolled Workforce

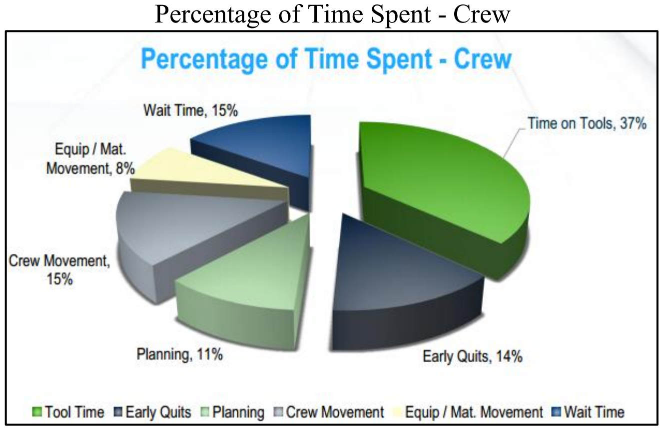
Effective materials and labour controlled are key elements for completing projects within budgeted costs and time delivery. Plemmons (1995) in Torrent *et al*. (2009) found the two most influential factors on material management were material availabilities and construction time lost directly associated with material issues. Material availability includes having the materials and equipment on time, at the right place, and in the right quantity. In fact, the non-availability of materials when needed on site has been identified as the most common and frequent cause of delays in projects

(Ibn-Homaid *et al*., 2001). Unavailable materials have a major cost effect on construction labours. Jang *et al*. (2009) reported that more than 6% of all construction labor costs could have been saved if materials and equipment had been available at the work site when needed. Even though the importance of material, equipment and crew availability are apparent, the focus of understanding and controlling an end-to-end supply chain process is still not executed in most mega-projects.

For instance, Jang *et al*. (2009) reported that trade foreman spent 20% of their time hunting materials and another 10% tracking purchase orders and expediting. Moreover, non-availability of materials can demotivate trade workers as they cannot perform their works, inherently affecting scheduling and planning.

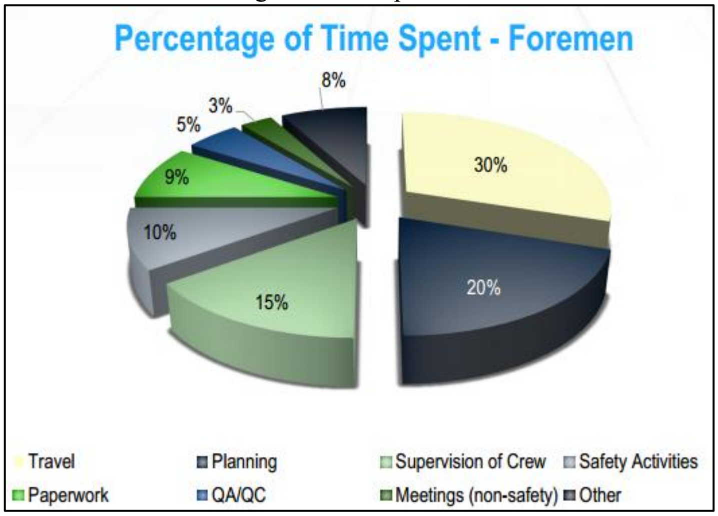
In addition to the authors above, Muehelhausen (1991) cited that 28% of the tradesmen's time were idled or non-productive due to unavailable materials and tools at time and place needed, and that work hour overrun was as high as 18%. In support of the various productivity claims that are enumerated above, the Construction Owner Association of Alberta (COAA) has derived a model of craft productivity based on field research. Both Figure 2.24 and Figure 2.25 illustrate the percentage of time-spent a crew will spend in an average-day engaged in various activities:

Figure 2. 24
Percentage of Time Spent - Crew



Bentley Construction Academy: AWP / WFP (2017)

Figure 2. 25
Percentage of Time Spent - Foremen



Bentley Construction Academy: AWP / WFP (2017)

Akinci *et al*. (2006) reported similar studies to the COAA and Construction Industry Institute (CII). For instance, the authors stated the following:

1. Missing and delayed information access constitutes 50% to 80% of the problems in construction;

2. 30% to 50% of the field supervisory personnel's time is spent on recording and analyzing field data;

3. Although the cost values of a project in terms of equipment and materials can add up between 40% to 60%, only 2% of the work on construction sites is devoted to manual tracking and recording of progress data;

4. Data are generally capture manually at site, and they depend on crews' subjective judgements in terms of choosing or not to report them.

Ohers studies estimates indicate that materials accounts for 50% to 60% of the project cost (Ibn-Homaid *et al*., 2001; Kini, D, 1999; Torrent *et al*., 2009; Young *et al*., 2011). Other authors like Silver (1988) broke down the costs of a project as followed: a) materials and equipment is 35% of a project, b) labour costs at 30%; c) indirect management at 20%, and d) engineering costs at 15%.

2.8.2. Factors Contributing to Success of this Research

There are numerous articles which state the poor performance at construction sites and any productivity improvement brings an important contribution to the construction industries. Wilson (2002) states four (4) important questions to ask in order to find out if a research brings a potential contribution to the construction's problematic managerial enumerated in this thesis:

- Is it true? Construction mega-projects are often completed with over budget, late in delivery, and is not a new recorded symptom in the Canadian industry;
- Is it new? The managerial problems expressed in this thesis have been ongoing for more than fifty (50) years;
- Is it interesting? This is perhaps the most important one question of all three (Gregor *et al*., 2013). Obviously, if the research is not interesting, there is no point to pursue the first two questions;
- Would supply chain integration during construction mega-projects have a substantial interest for the industry communities? Although integrating supply chain processes as standard routine, it doesn't necessarily mean the decisional stakeholders will adopt all the processes.

The construction industry, especially mega-projects, is plagued by the symptomatic managerial problems on how to control costs and deliver on-time during the construction execution. Today, these problems remain a nightmare to project managers. Literatures and technical journals offer several solutions that can "partially" solve these managerial problematics. For instance, in "Reinventing Construction: A Route to Higher Productivity" in *McKinsey & Co.* (2017), proposed seven (7) areas that could increase construction productivities:

1. Reshape regulation;
2. Rewire contracts;
3. Rethink design (modular construction);

4. Improve procurement and supply chain;
5. Improve onsite execution, such as using data analytics;
6. Infuse technology and innovation, with intelligent tablets;
7. Reskill workers.

This thesis has selected the route of integrating supply chain processes into construction project phases as one potential solution to the managerial problems. In fact, one can ask: (1) will integrating supply chain processes into construction mega-projects thwart these managerial problems and subsequently assist the construction communities? (2) is understanding the underlying of supply-chain processes will make a substantial contribution toward finding a solution to the managerial problems in the construction industry?

This integration does not necessarily assume it is the best of all seven (7) options, nor it is the holistic solution to the managerial problems presented in this thesis. However, the researcher thinks it is worth exploring the managerial problems with the integration of a supply chain framework.

2.8.3. Construction Problems & Solution Maturity

In accordance with Gregor *et al*. (2013), the research contributions toward this thesis' managerial problems depend on two factors: a) problem maturity and b) solution maturity. For instance, over budget and late delivery during construction mega-projects are well known problems across the global construction industry, hence these managerial problems can be described as highly mature.

There exist also several solutions available to the construction industry in order to counteract these managerial problems, however, very few of these solutions are seldom applied by themselves. This thesis proposes a solution to the managerial problems by modifying the SCOR Model into a better and more responsive design (artifact), tailored for mega-projects. This design (artifact) shall be demonstrated in

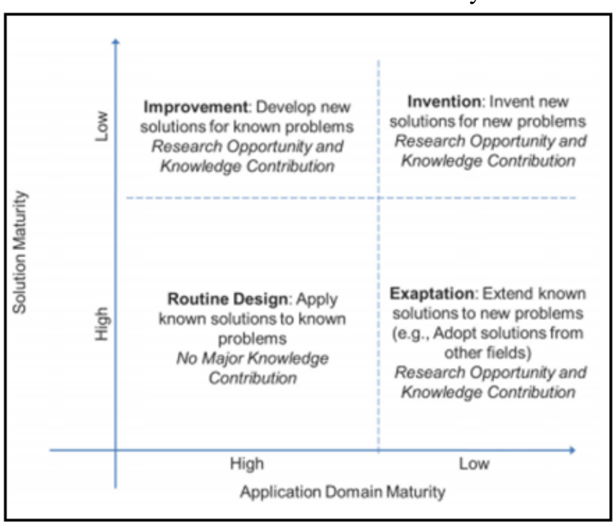
Chapter Four as having one of the maturity factors: (1) an improvement, (2) invention, (3) routine design, or (4) exaptation.

2.8.3.1. Improvement from the SCOR Model

According to Gregor *et al*. (2013), most of the solutions in management information systems and information technologies belong to the category of improvement. Illustrated by Gregor *et al*. (2013), Figure 2.26 depicts the problem maturity and the solution maturity, on the x-axis and y-axis respectively.

Using Gregor's x and y-axis, the proposed artifact (model = design) in this research, which integrates supply chain framework in construction project management, can be evaluated as an improvement to the current industry standard (e.g. SCOR Model). Hence, the thesis' artifact is a new design, and is by itself an improvement over the SCOR Model. Details of the artifact's improvement are detailed in Chapter Four.

Figure 2. 26
Solutions vs. Problems Maturity



Gregor *et al*. (2013)

2.8.3.2. Invention from the SCOR Mode

According to Gregor *et al*. (2013) an invention, is a radical breakthrough and a clear departure from the accepted way of thinking and doing. Therefore, the thesis' artifact can't be considered an invention, since the researcher states that the artifact is first and foremost, an improvement. Moreover, an artifact can only be considered as inventive when the artifact itself, can be evaluated and re-evaluated through mid-range theory in a real-world context. This is not the case for this research, since the artifact in this thesis, is the first attempt to present a constructive design, tailored for the construction industry. The artifact was also only tested at one site.

2.8.3.3. Routine Design from the SCOR Model

The routine design applies known solutions to known problems, and there is no major contribution to knowledge. In other words, routine design occurs when existing knowledge for the problem area is well understood, and when exiting artifacts are used to solve the problem (Gregor *et al.,* 2013). Since we know the construction industry has been criticized for delivering projects late and over budget for decades and not much has changed today, the concept of routine design cannot be applied for solving this thesis' managerial problems.

2.8.3.4. Exaptation from the SCOR Model

In terms of exaptation, the knowledge contribution is obtained when design knowledge that already exist in other fields (e.g.: other than construction), is extended or refined so that it can be used with new problems in other fields like construction. Often these new opportunities open the way for the exaptation in the applicable field of research.

The SCOR Model which is frequently used in the manufacturing sectors would contribute to an expectation knowledge, if it would be able to solve the problems in mega-projects. However, as explained in the improvement contribution above, the SCOR Model, which perform well in the manufacturing sectors, has several flaws in relating to engineering and construction activities. Thus, the researcher had to modify the original model (SCOR) into a new artifact, taking into consideration the detailed activities specific to the construction environment.

Finally, the literatures note several concepts that are similar to Gregor *et al*. (2013). For instance, Savaransky (2000), Sternberg *et al.* (2002) and Stokes (1997) presented their axis on creativity and innovation, where the processes are examined by which existing knowledge is transformed into new, useful products. The approach of using the SCOR Model as the basis and improving it with a new artifact, which covers all activities and phase of construction project management, is in line with this thesis and the authors above.

In summary, the researcher states this thesis brings an important contribution to the construction communities, by closing a gap on literature and challenges the integration of supply chain driven process into mega-projects. are commonly driven by engineering and construction approaches. This research aims to answer these important knowledge contributions:

- The managerial problematics during mega-projects are true;
- On a scale of maturity, the proposed artifact (design) is observed as an improvement over the current literature;
- The proposed integration of supply chain processes into a construction model is one of the seven (7) proposals offer by the firm *McKinsey & Co* (2017);
- The approach of modifying the SCOR Model into a Construction Performance & Productivity Model is interesting;
- The proposed artifact (design) is a new solution covering all phases of construction project management.

THIRD CHAPTER
OPERATIVE FRAMEWORK

3.1. METHODOLOGY

The first part of the research was the implementation of the review of literatures, covering several fields of studies. At the beginning of the research, supply chain management was studied with a focus on best practices in manufacturing's logistics and transportation. Then, as the research advanced, the researcher leaned its efforts on the better understanding of management information systems with a concentration on tracking technologies and supply chain practices and processes.

The next step by the researcher was the reviewed of journals and technical papers in business intelligence, especially in the fields of supply chain, warehouse management and project management. At last, the researcher homed its final field of investigation in construction project management and mega-projects. Overall, the review of literatures included the field of supply chain management, logistics, transportation, management information systems, business intelligence and analytics, warehouse management and construction project management.

In the second part of the research, the researcher conducted two residences in order to validate construction constructs. The two residencies adopted the methodologies of a Participant Observation with a global engineering firm and an Action Research that took place during a mining construction project, where the researcher worked for a construction management team. These two (2) residencies offered to the researcher the opportunities to explore the construction industry in a highly immersed environment and to understand the complexity of real-life construction world. In support of this last statement, Vaishnavi *et al.*, 2004 stated the methodologies above offer a lens or set of synthetic and analytical techniques or perspectives (complementing it with positivist, interpretive and critical perspective) for performing research in the field of management information systems. In addition, Baarts (2009); Thiel (2013); Shipton *et al*. (2014); and Vaishnavi *et al*. (2004) believe that construction literatures should draw on ethnographic methods that help better understand the lived experiences and practices of trades in project settings. Nonetheless, the researcher did not come across studies, where researchers had been immersed for a prolonged period in a real-life construction field.

Understanding the complexity of mega-projects' environment, the researcher moved on into the third part of the research's methodologies, where a second review of literatures were undertaken, with an emphasis on models and theories applicable to construction mega-projects. As mentioned in the previous chapter, several kernels theories were studied in relation to construction project management and mega-projects.

The researcher eventually rested its modeling and theoretical studies on selecting the approach of the Design-Science Research. Design-Science Research (DSR) has drawn increasing attention in recent years as it has become an important research tool in management information systems (Kuechler et al., 2008). The approach of Design-Science Research addresses important real-world managerial problem in unique or innovative ways, such as this thesis' problems, and can provide a clear contribution to construction project management.

Design-Science Research represents the structuration duality, where conducting a design-only or theory-only research is not suitable either way, as neither one would contribute to knowledge. In fact, journals like MIS Quarterly expect a clear theoretical contribution from research articles with empirical findings or a detailed description of an artifact (Gregor *et al*., 2103). Detailed of Design-Science Theory is further described in this chapter.

Following the selection of the DSR, the researcher conducted series of semi-structured interviews and one survey, in line with the Design-Science Research's two (2) paramount's views and objectives: building an abstract (design) and theorising with a mid-range theory, assisted by kernel theories. The abstract for the DSR is known as the Construction Performance & Productivity Model or by the acronym of CPPM.

The last part of the research was testing through quantitative and qualitative analysis the abstract's reaction to four (4) types of construction contracts. The abstract "*CPPM*" leaned on adopting a supply chain framework, which includes engineering and construction management in co-existence with procurement, cost control, workers management and project complexities. Furthermore, the abstract "*CPPM*" focuses its effort on tracking performance and productivity across all phases of construction project management, by measuring performance attributes and metrics related to seven (7) project activities, including:

- Procurement Reliability;
- Procurement Responsiveness;
- EPCM Agility;
- Project Control;
- Employee Management;
- Project Complexity;
- Project Integration.

Thus, in order to understand real-life settings, this research which had the benefit to have been integrated in construction sites over several years, leans on the truth of relativism, the ontology of constructivism, the epistemology of subjectivism and the flexibility of pluralism, along with the Design-Science Research.

3.1.1. View / Truth: Relativism

As the reality is represented through the eyes of participants in relativism terms, it may be difficult to set the boundaries between participating and observing (Palsson, 2007).

In fact, through relativism, the researcher may easily adopt the blindness against negative inputs, and subsequently lacking the outside perspective of other important stakeholders. Hence, the researcher may well adopt an internal perspective (e.g. bias to supply chain approach) without critically examining granted information and accepting facts.

The reasons for conducting two (2) residencies through a Participative Observation and an Action Research reflect on the ontology of relativism during construction mega-projects. Hence, relativism in construction can be summarized as followed:

- In relativism, the research process is viewed as generating working hypotheses (constructivism) that evaluate every day activity, rather than immutable empirical facts (positivism);

- In relativism, different approaches from different individual make up alternative ways of looking at the world and provide a summation of activities;

- Because different cultures and societies have different conceptual systems in related matters, reality can be constructed only by means of a conceptual system, and therefore, objective (positivism) reality can't exist;

- Reality is represented through the eyes of participants, such as during Action Research and Participative Observation;

- Stakeholders working at a construction site are not element derived from an organisational theory. They have their own objectives, goals, managerial problems, wishes, perceptions and interests;

- Converting the social world of a construction into an artificial laboratory such in objectivity (positivism), has nothing in common with the real-life experience related to construction site;

- The emphasis place on positivism is wrong and unjustifiable, for it can't capture the real meaning of social behaviour, especially when a construction site is composed of thousands of construction workers, foremen, superintendents, managers and so on. Hence, pure objectivity is not sought for this doctoral thesis.

3.1.2. Ontology: Constructivism

In relativism, there is no single way in which to undertake a research and represents its findings, as different approaches produce different kinds of knowledge. Hence, ethnographic approaches such as Participant Observation and Action Research are generally a concept of reality based on constructive knowledge acquired lived into a field of study, such as the researcher taking part in the construction activities as manager.

Some authors (Atkinson *et al*., 2001; Jackson, 1983) state their supports to this epistemological fact, which such methodologies like Participant Observation and Action Research, grounded into specific environment and committed to lived experience and exploration of particular social or cultural settings. The two ethnographic methods for constructing knowledge were selected for understanding the managerial problems and the related level of supply chain integrations during construction mega-projects. Hence the two residencies homed the researcher with the following searches:

- A Participant Observation methodology, which studied the amount of supply chain process activities during construction project management;
- An Action Research method intended to investigate the level of inventory management accuracy at a mining construction site conducting a mill upgrade.

The researcher, like Shipton *et al*. (2014) believes these two methodologies that were used above during the residencies represented the true voices and daily realities, with all construction stakeholders (corporate, site managers, contractors, engineering firms and tradesmen). The knowledge of this research is therefore socially constructed. The participants that took part in the observations and action research are viewed at helping to construct along with their knowledge, the reality of the environmental settings which they operate in. Moreover, there is an ontological assumption that underlie ethnography whereby social reality is presented in a dynamic way, not statically proving a theory or law (van Maanen, 1988). As such, these two methodologies represent a constructive picture of both pre-construction and construction execution. For instance, they provide the following representations:

- The Pre-Construction Phases are represented through a Participant Observation: An engineering-driven culture, which are leading the conceptual, front-end planning and detailed engineering phases prior to the execution of construction;

- The Construction Execution Phase is illustrated by an Action Research: A construction-driven culture located at construction sites, in charge of executing the detailed engineering plans, commissioning the works and turning it over to the owners.

Additionally, other authors like Popper (1978) and Habermas (1984) view the ontological perspective of constructivism as a pluralist form of realism in which three (3) separate domains are recognized. For instance:

- World 1 (instantiation): The objective world of materials;

- World 2 (subjectivity): The subjective world of mental states such as ideas and experiences of the designers, in this case, the researcher's subjective views and its preferred approach (supply chain) within the world of construction project management.

- World 3 (abstract): The abstract world of human-made entities such as languages, theories, models, constructs, etc., such as the proposed Construction Performance & Productivity Model.

3.1.3. Epistemology: Subjectivism

Central to the representation of social reality in relativism and constructivism, is the role of the researcher to understand its subjectivity towards his or her research and attempt to be ethnically neutral. In fact, choices and biases which influence fieldwork observations shapes this representation of the selected reality and the writing of the subjectivism (Shipton *et al*., 2014). For instance, the background of the researcher is supported by a M.Sc. in logistics, along with a doctorate studies in management information system, with a profile in construction management and supply chain management.

The researcher thus recognizes that pre-construction phases to project management are engineering-driven and led obviously by engineers which have no intent, in general, to implement supply chain processes throughout the various activities of conceptual, front-end planning and detail engineering activities. Similarly, the researcher understands the construction phase, including execution, commissioning and turning over, are subsequently driven by construction stakeholders, leaving little room to implement a higher level of supply chain integration. Correspondingly, the researcher recognises its biased views and that one of many ways to control the managerial problems of cost overruns and late deliveries of mega-projects, is by attempting to seek a higher level of supply chain integration during construction project management.

As a result, the researcher understands there is no external reality independent of human conscious, hence the reality of a research can't be defined objectively, but only subjectively. This acceptance by the researcher has been widely acknowledged with the recognition of ethnographic truth as inherently partial and subjective (Clifford, 1986).

3.1.4. Flexible Design: Pluralism

Design-Science Research, which goes beyond the constructivism of this research, has a pluralistic viewpoint, and acknowledges that design-science aims at providing general design solutions for a general class of problems (Baskerville *et al*., 2015). There are many studies that use this kind of flexible design method approach in management information systems (Baskerville *et al.,* 2004; Burati *et al*., 1992; Chan *et al*., 1995; Fellows, 2010; Gardiner *et al*., 1992; Love *et al*., 2000; Susman *et al*. 1978; Senaratne *et al*., 2008). Pluralism and diversity of DRS are already recognized in both management information systems (Landry *et al*., 1992; Robey 1996) and in action research (Baskerville *et al*., 1998).

The cyclical nature of a Design-Science Research (DSR) demands different evaluation at different stages of progress. The pluralism of Design-Science Research creates challenges because of the differing sets of criteria, it needs to evaluate, and which are represented by knowledge production. Consequently, when using DSR, one must think about multi-paradigmatic, thereby requiring differing criteria to justify the knowledge produced at differing moments. These pluralism results provide the researcher confidence in the polymorphic way, in which they generate new knowledge, enabling them to better refine kernel theories into mid-range theories in order to justify their research questions and findings.

Thus, the knowledge production for this research proceeds from the intertwined relation between design and science, resulting in a polymorphic knowledge production. In fact, the nature of the polymorphic knowledge production for this thesis evolved over 2011 through 2017. It began with the Participant Observation and the Action Research.

In summary, the polymorphic knowledge used differing criteria to justify the knowledge produced during the seven (7) years spent in the field. Hence, DSR is a mixture of qualitative and quantitative methods, which promotes the foundation of this research design, supported by various kernel theories. This pragmatic approach helps to reinforce and validate the findings. It provides opportunities to gather information from a vast variety of individuals such as senior management in construction and engineering, field superintendent and tradesmen.

3.2. INTRODUCTION TO DESIGN-SCIENCE RESEARCH

Design Science Research (DSR) has drawn increasing attention in recent years as it has become an important research tool in management information systems (Kuechler et al., 2008). Design-Science Research addresses important real-world managerial problem in unique or innovative ways, making a clear contribution to the real-world application environment from which the research's problems are drawn from (construction mega-projects).

DSR involves learning through the act of building. Design-Science Research is a body of intellectually tough, analytic, partly formalizes partly empirical, teachable doctrine about the design process (Simon, 1988). Significant efforts have sought to establish the foundations of DSR as a research paradigm (Hovorka, 2010; Iivari, 2007) and to provide an epistemological positioning (Goldkuhl, 2012; Niehaves, 2007) for this methodology.

According to Hevner *et al*. (2004), Design-Science Research seeks a solution to a real-world problem of interest in practice. For instance, the construction industry seeks to find a solution to the ever-consistent dilemma of completing a project over budget and late in scheduled deliveries. Overall, the design theory doesn't tag a single problem to a single theory but rather a class of problems to a class of theories (Walls *et al*., 1992).

In support of DSR, Venable *et al*. (2016), stated that DSR is also a paradigm in a sense similar to other scientific paradigms such as constructivism and positivism. While there are different ways to characterise such paradigms, the prescriptive and functional nature of DSR demands a distinction that is more practical (design-based) and less philosophical (theoretical-science-based). The design's pragmatic and episodic approaches in DSR welcome changes, and also holds true for science, where it is inextricably bound to the testing and refining its kernel theories.

According to Baskerville *et al*., (2015), the notion of a design-science study broadly represents four (4) explanations, in which the paradigm operates. The four (4) explanations are:

1. A science research project in the field of Construction Management, of which literatures lack relevant and field-friendly models measuring activities throughout all phases of mega-projects;

2. An artifact design such as the proposed Construction Performance Model (CPM) in this research. The CPM is a set of metrics to measure construction performance and productivity;

3. The production of new knowledge from design-and-development, such as the final Performance Attributes, its Level I, II and III metrics as well as its selected KPIs for the mega-projects;

4. The diffusion of reports or articles describing this design-science research project.

For others, Design-Science Research (DSR) is a methodology and problem-solving paradigm that seeks to create innovation that define the ideas, practices, technical capabilities, and products through which analysis, design, implementation, and use of management information systems (MIS) can be effectively and efficiently accomplished (Tsichritzis, 1997; Denning, 1997).

The term Design-Science Research is by itself contradictory. Such apparent contradictions seem to shape the essence of this newer methodology and research paradigm. Its objective is to develop researches that makes meaningful design and science contributions in a manner that is beyond just the science of design or designing with science. It involves the creation of knowledge through the analysis of a given design problem, synthesis of solutions based upon this analysis, and evaluation of the solution. Much of the debate centers on whether, in addition to artifacts, a theoretical contribution is central to, or even necessary for, design-science studies (Baskerville *et al.*, 2010; Gregor *et al.*, 2013; Österle *et al.* 2010).

Echoing the supposed contradiction between design and science, this debate distinguishes between the research contributions demonstrated by the utility and elegance of the design solution, as represented by the resulting artifact, and the contrasting creation of abstract knowledges (Goldkuhl 2012; Gregor *et al.*, 2013). For example, the objective of the proposed Construction Performance Model (CPPM) in this thesis doesn't target a theory, but moreover, it attempts to fill the void in construction management literature in providing a relevant and field-friendly design measuring the construction project management activities of mega-projects.

The contradictions between design and science are epitomized in the failed efforts to "*scientize*" design with design methods (Cross, 2001). Grant (1979) asserts that "the act of designing itself is not and will not ever be a scientific activity," suggesting that a method might be vital to science, but not to design.

Although design and science share the same subject matter (e.g. the world) and produce artifacts (e.g. theories), their aims, methods, and criteria are quite different (Galle *et al*., 2014). Design is concerned with synthesis, whereas science is concerned with analysis (Simon, 1996). Design-Science Research is unique because the collision of both making and knowing in a single research study. Understanding knowledge production in design-science requires more than just the distinction between know-how and know-why (Kogut *et al*., 1997). Hence, this research explicitly recognizes that Design-Science Research processes will change as the observations are being gathered due a pragmatic view related to the managerial problems. This methodology/paradigm helps the researcher to recognize changes in the way the researcher justifies any knowledge produced.

Many MIS studies in the field has lacked relevance for the practitioners' community, which could be surmised from the fact that very few researchers from the MIS discipline have ended up working in business (Osterle *et al*., 2010). A thriving Management Information Systems (MIS) using design-science can help integrate the contributions of myriad other MIS research paradigms into these important and continuously earth-shaking information technology innovations (Goes, 2014). Given its importance and relevance to management information systems, and the fact the researcher is conducting this thesis at *l'Université de Sherbrooke*, in the department of *Système d'information et méthodes quantitatives de gestion*, it is indeed worthwhile to understand how to conduct a good design-science.

Venable (2006) shows in Figure 3.1 the framework for the relationships between the activities of Design-Science Research in Information System (IS) and the theory development. This framework can be associated with this thesis in such ways:

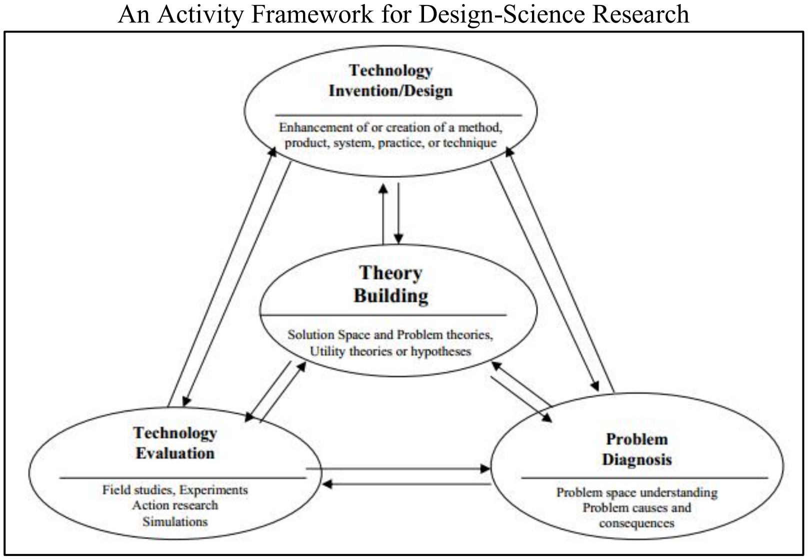
1. Problem Diagnosis: The construction industry is plagued with mega-projects that are completed over budget and delivered late in schedule;

2. Technology Evaluation: Through observations, actions, interviews and surveys;

3. Theory Building: The building of the Design-Science Theory for Construction Project Management spans form analysing narrative thinking (constructs) and recorded views (e.g. RBV, Design, Science and Knowledge) to explanatory kernel theories outside the IS field (Dynamic Capability, Structuration, Contingency, Co-Alignment and IT Adoption);

4. Technology Invention / Design: The CPPM's artifact is the summation of the three (3) elements hereinabove.

Figure 3. 1
An Activity Framework for Design-Science Research



Venable, 2006

Thus, in order to face the complexity of decision-making in the world of construction management in mega-projects, the kernel theories relate to various set of theories in cognitive, organisational and behaviour science that will assist in developing a design for the managerial problem. As mentioned in the previous chapter, the kernel theories which makes up the part of the theories, which are part of the Design Science Research's paradigm are:

- Theory of Dynamic Capability;
- Structuration Theory of Duality;
- Co-Alignment Theory & Contingency Theory;
- Theories of Adoption of Information Technology.

These kernel theories revealed parallel significance with the constructs stated in the first chapter. In a sense, matching constructs, semi-structured interviews and survey through a correlation with the kernel theories reviewed in the literature are an attempt to introduce narrative thinking for the DSR's framework – based on supply chain processes (Davies *et al*., 2006; Kuechler *et al.* 2008; Lethbridge *et al*., 2003).

Kernel theories originate outside the science of Information System (IS) and many kernel theories are natural science or behavioural science theories that explain and predict (Walls *et al*., 2004). Kernel theories are explanatory and are often considered to be only advisory and temporary to the design effort. Furthermore, Vaishnavi *et al*. (2004) amplified that kernel theories are to inform the design effort and in turn, refined and developed the design theories for that artifact into mid-ranges theories. Lastly, design theories which provide explicit prescription on how to do something, for instance through a model, correspond to the design and action theory developed by Gregor (2006) and Walls *et al*., 2004).

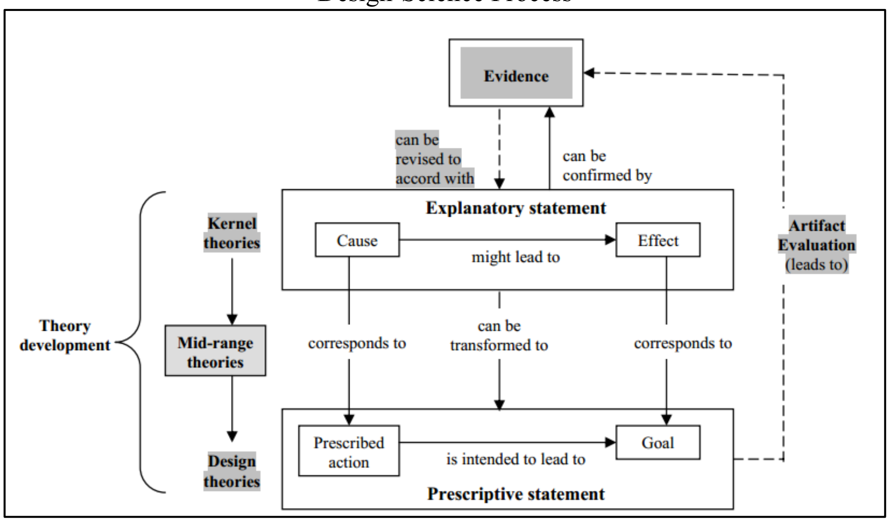
As cited in Kuechler *et al.* (2008) and Markus *et al*. (2000), this thesis must accomplish two (2) things in order to serve as an existing proof, of the potentially close relationship between Design-Science Research (DSR) and its related kernel theories:

1. The relationship of DSR and its theory: How should a theory informs or should be instrumental in developing and refining a theory per se?

2. The relationship between the kernel theories and the mid-range DSR theories. The kernel theories that are refined into mid-range theories for this thesis are taken from the RBV, the Dynamic Capability, the Information IT Adoption Theory, the Contingency of the Fit Theory, and the Structuration Theory of Duality.

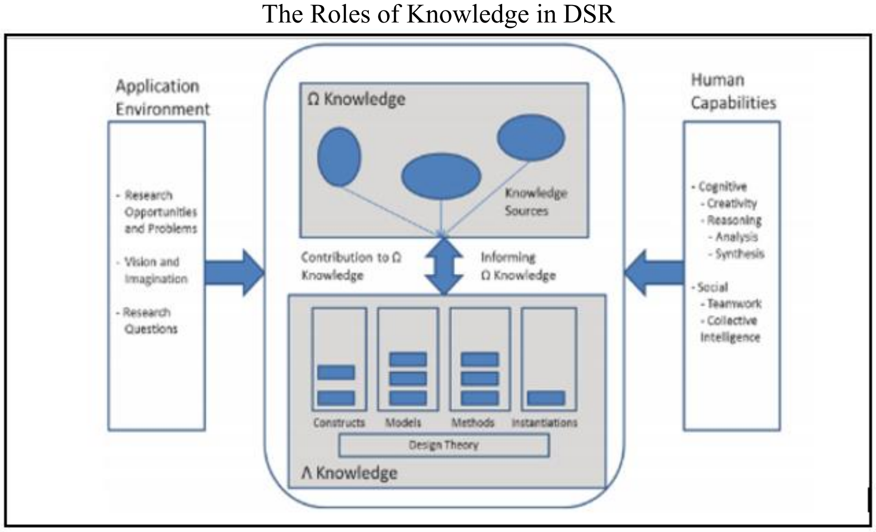
The process relationship between kernels theories and a design theory is presented in Figure 3.2 and Figure 3.3, by Goldhuhl (2004) and Vaishanvi *et al*. (2004) respectively.

Figure 3. 2
Design-Science Process



Goldhuhl (2004)

Figure 3. 3
The Roles of Knowledge in DSR



Gregor *et al*. (2013)

Overall, the focus of the thesis's design is to measure the level of supply chain robustness within the activities of construction project management, through performance attributes and KPI's productivity. The abstract (design) known as Construction Performance and Productivity Model (CPPM), aims at changing the existing situations in construction mega-projects into a more effective and efficient ones by controlling cost, schedule and quality throughout all phases of a project. By doing so, the CPPM attempts to control the managerial problems that have plague the construction industry for more than fifty (50) years, and in the same time, utilizing the researcher' knowledge and experience when working at construction sites.

The research' artifact (design) proposed in this thesis is named the Construction Performance and Productivity (CPPM). Primarily, the artifact is built with the approach of a supply chain framework. It is a design that doesn't attempt to provide a law-like explanation or theory, such as required in science. The CPPM rather offers a knowledge with explanations that are contextualized in human behaviour found at construction sites (the environment) and contingent on carefully bonded ranges of philosophy and/or probabilistic claims of causality (Baskerville *et al.,* 2015).

This thesis demonstrates throughout the seven-year period, as an episodic event of a true Design Science Research. To some extent, the development of the design named Construction Performance & Productivity Model was at first, exploratory in nature (participant observation and action research), and got stronger in time, with data supporting the final design (DSR's artifacts). Differing positions or opposing views in Design-Science Research fall on the tension between the goals of design versus the goals of science (theory). According to Goes (2014), the main concern with the Design-Science Research is its bias toward a designed-based and "not to test or create new theories" for science, although the constructs and methods that are observed during the designs can lead to theory formulation. Moreover, the objective of the design for this research is to create knowledge through meaningful solutions, like artifacts, that will survive rigorous validations through proof of concept, proof of use, and proof of value.

Thus, this thesis must make the efforts to articulate and analyze the roles of a design and the roles of kernel theories, during the various stages of design-science studies, which are episodic in essence (Goldkuhl 2004; Gregor *et al*., 2007; Vaishnavi et al., 2007; Venable *et al*. 2014; Walls *et al*., 1992).

3.2.1. Descriptive Representation of the Design Theory

When incorporating a descriptive (e.g. what) representation with supports of observations, actions, interviews, surveys and in supported with an operational framework in the form of contracts, the representation of the situation helps subsequently promoting a prescriptive (how) knowledge, in such a way of producing an artifact. The descriptive what-knowledge begins with one or several managerial problems involved in construction mega-projects. For their parts, Gregor *et al*. (2013) presented the descriptive knowledge into two categories:

- The description of natural, artificial and human-related phenomena such as observations, classifications, measurement, cataloging;
- Sense-making is represented by natural laws, regularities, principles, patterns, theories.

3.2.2. Prescriptive Representation of the Design Theory

From the prescriptive base, it is useful to investigate artifacts and other design theories that have been used to solve similar managerial problems in construction. Chapter Three shows the make-up of prescriptive knowledge, which includes the constructs, the SCOR model as the basis of the design, results from the interviews and survey, and the end product in the design's artifacts. Supporting the prescriptive representation of the design theory, March *et al*. (1995) define four (4) types of prescriptive knowledge:

1. Constructs such as concepts and symbols provide the vocabulary and symbols used to define and understand problems and solutions. For instance, Chapter One offers seven (7) constructs which are particular to the construction industry;

2. Models which are a designed representation or a semantics of problems and possible solutions. This thesis at firs, used the Supply Chain Operations Reference (SCOR) Model, which has proven successes with several manufacturing industries. However, as literatures state, the SCOR Model is not fitted in construction management. Therefore, the SCOR Model was enriched and minimized (reduced) into the Construction Performance & Productivity Model (CPPM);

3. Methods can include algorithm, practices, technique, processes (e.g. supply chain processes) for performing a task (e.g. measuring procurement reliability or responsiveness);

4. Instantiations, which centre on the physical realizations that act on the natural world, such as in the forms of systems, products, processes or improvement.

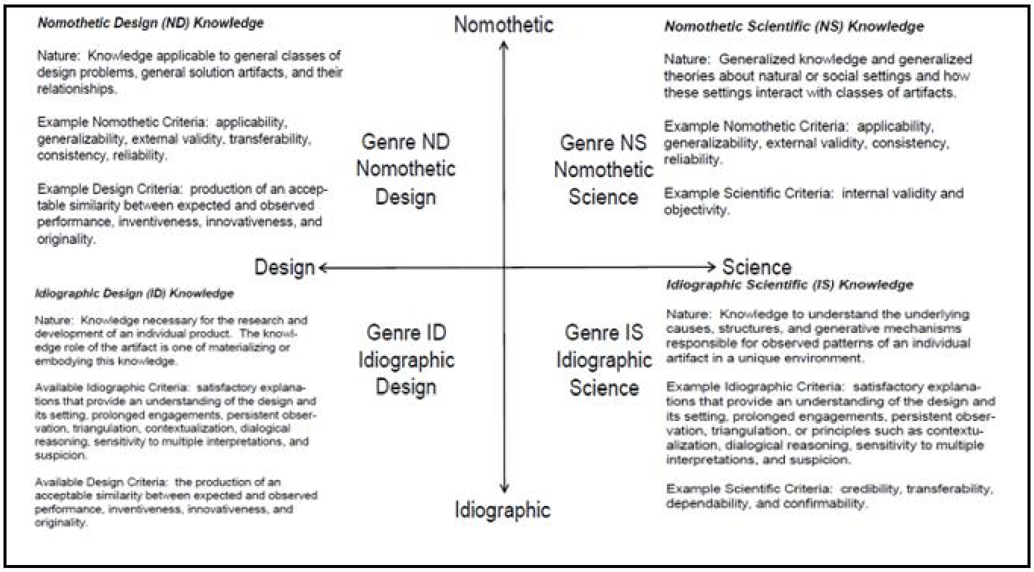
The last category of the prescriptive knowledge in the design theory is the abstract, a coherent body of prescriptive knowledge that describes the principles of form and function, methods, and justificatory theories (Gregor, 2006; Gregor *et al*., 2007).

3.3. DESIGN VIEWS OF DSR

The framework of the Design-Science Research includes both knowledge goals (design and science) and knowledge scope (nomothetic and idiographic). To investigate and produce knowledge activities through a DSR settings, the researcher used a style of thinking, which Hacking (2012) refers to as “genres of inquiry”. The investigation method of genres of inquiry assists in explaining the knowledge activities in inventive forms of scientific inquiry. According to Hart (2000), each genre of inquiry asks different questions about lived experience and requires different methods of inquiries. So, different genres of inquiry not only invoke different philosophical assumptions, they invoke different styles of articulation (Baskerville *et al*., 2015).

There are overall, four (4) different types of genres inquiries, based on the two dualities of the knowledge goal “design versus science” and the knowledge scope “nomothetic versus idiographic". For this thesis, the framework utilised for this Design Science Research is obtained from the article written by Baskerville *et al.* (2015) and is presented in Figure 3.4.

Figure 3. 4
Genres of Inquiry Framework for Design Science Research



Baskerville et al. (2015)

Hence, through rigorous observations and actions based on the achievement of cumulative knowledge over many years (2011-2017), obtained during office and field employment, the researcher employs a Design-Science Research methodology to design and test its Construction Performance & Productivity Model to justify new knowledge in construction of mega-projects. To justify such knowledge, in accordance with Baskerville *et al*., (2015), the researcher must consider such questions as:

- Are the stakeholders sufficiently engagement with the activities? The main participants for this thesis included a wide variety of construction stakeholders, including project directors, project managers, and construction specialists;
- Are the observations sufficiently persistent? The constructs proposed in Chapter One were derived from Participant Observations, Action Research, semi-structured interviews and survey;

- Was the reasoning sufficiently dialogical? The elements of the CPPM include exchange between different points of views with various senior managers;
- Was there enough sensitivity to multiple interpretations? The final analysis of performance & productivity robustness (interviews) versus the selection of top tiers (survey) offers a large amount of multiple interpretations, which are presented in Chapter Four.

In general, Design-Science Research doesn't aim at analyzing a construction phenomenon, or showing factual characteristics, in order to be able to identify causal relations. Instead, the design in DSR attempts to combine qualitative, quantitative and analytical modes of thinking with inventive modes focusing on developing artifacts, in order to solve complex, multivariate problems in elegant and unique ways. Hence, the design part (e.g. CPPM) of the Design-Science Research has become a very practical know-how that cannot be relegated down to an attempt to prove a theory (Baskerville *et al.,* 2015). Reflecting the more constructivism approach, or less positivist one, the criteria for finding the truth in a design-based model is based on the design's credibility is found in its confirmability (Guba, 1981).

Reflecting the paragraphs above, design is paramount, as a valuable artifact is produced (Hevner *et al*., 2004; March *et al*., 1995; Nunamaker *et al.*, 1990).

3.3.1. Nomothetic Design

Commonly, a nomothetic design (ND) can be expressed as more generalizable design theories (Walls *et al*. 1992) or general design principles that are applicable to a class of problems (Markus *et al*. 2002). Such nomothetic representations explain why a generalized set of requirements would be satisfied by a generalized set of object features (Baskerville *et al.,* 2015). An example of a nomothetic design (ND), for instance, is when the researcher compares and analyzes how other industries have designed solutions to these other / similar problems. In this instance, a knowledge production is likely to involve a nomothetic design as this knowledge is transferrable from one industry to another one.

The CPPM design falls into this nomothetic design as it attempts to solve two (2) global managerial problems when executing construction mega-projects that occurs on all five (5) continents: First, mega-projects are often over budget and second, projects are late in schedule deliveries. It is important to note the researcher's proposal in utilising the CPPM design is only one of several potential attempts to improve the current global situation.

3.3.1.1. Nomothetic Design Goal & Scope

In nomothetic design, knowledge processes aim at producing general knowledge about a class of design. In fact, the CPPM design and its 350+ metrics are not set in concrete from projects to projects. On the contrary, the users of this design can decide to draw out metrics, unique to a project. Thus, the flexibility of the CPPM reflects the strength of this evolving design at producing a general knowledge and reflects the continuous improvement requirement which global businesses face today.

3.3.1.2. Nomothetic Design Nature of Knowledge

According to Walls *et al* (1992), nomothetic design produces knowledge about design elements that are more general, higher-level requirements (such as meta-requirements that are more abstract. For instance, the seven (7) performance attributes found in the CPPM design will provide knowledge production and devise a course of design action in a manner that is applicable to a construction problem. Baskerville *et al*., (2015) states several examples of artifacts gain from these nomothetic designs. These examples can be constructs, methods, models, design principles, technological rules, and design theory.

3.3.1.3. Nomothetic Design Quality Criteria

Examples of quality criteria for nomothetic design (ND) relate to knowledge including a design that can meet the following criteria: applicability, generalizability, external validity, transferability, consistency, reliability, dependability, the production of an acceptable similarity between expected and observed performance, inventiveness, innovativeness, and originality (Guba 1981; Jones 2009; Martin 2009; Petroski 2009). This chapter describes various justification criteria, of which the CPPM design offers through its Design-Science Research paradigm.

3.3.2. Idiographic Design

Idiographic design (ID) provides knowledge that is applicable to a particular problem setting or an artifact which devises a course of action that changes an existing situation into a preferred one (Baskerville et al., 2015; Simon 1996). In line with idiographic design, the micro-intent of the CPPM design is to control the project costs, the timeline of the schedule delivery, performance and productivity and the efficiency of a supply chain at construction sites.

As stated earlier, the objective of this research is to identify which metrics have the strongest robustness in terms of performance and productivity levels, and eventually use them as part of the Construction Performance & Productivity Model for particular job site. Similarly, to the nomothetic design (ND), the idiographic design (ID) offer the choice to the user to decide which metrics should be measured, depending of the project which the user is working on. For instance, this research has adapted the CPPM design into four (4) different contractual situations involving: (1) owners, (2) contractors, (3) lump sum contract and (4) time & material contract. In this case, the researcher was engaged in adapting various level of designs, based on metrics specifically retained for a project. Consequently, the flexibility of the CPPM design reflects the strength of the evolving idiographic design (ID) and the local environment which it performs in. Overall, the CPPM's idiographic design (ID) provides three (3) insights.

First, it provides insights from the details and considerations that can be availed through interactions or experience within the designs (Hook *et al*. 2013). In this effect, the researcher had free access to a mega-project site and was able to observe constructs related to various elements of the project itself. For instance, the researcher observed and measured through a Participant Observation methodology, the level of using supply chain's activities that were present during the project phases. Then, the researcher eventually moved into a job site of a mega-project and through an Action Research approach, attempted to promote the benefit of inventory management's best practices.

Finally, the researcher attempted to improve performance and productivity at job sites using the SCOR model, but realised the weaknesses of the model, confirmed in the literatures, when used within the construction industry. Subsequently, the elimination of some of the original SCOR's Performance Attributes and metrics were made and replaced by other metrics and KPIs that were best suitable to construction. Detailed of the CPPM's performance attributes and metrics are shown in Appendix D.

Second, idiographic design insights can provide a basis for guiding a design for broader usage (von Hippel 1986). The hope for this thesis is to eventually improve the proposed design (CPPM) and promote it to various construction environment such as mining, oil & gas, buildings and infrastructure sectors. Moreover, the design itself reacts to owners or contractors, to lump sum (Design-Built) contracts or to time & material contracts.

Third, as stated by Järvinen (2007) and Winter (2008), an idiographic design (ID) in the paradigm of Design Science Research provides a mechanism for validation of a design through an instantiation, for example, in the form of a prototype. In agreement with the two authors, the CPPM design is a form of instantiation, which provides an instance through its Performance Attributes, Level I, II and III metrics.

3.3.2.1. Idiographic Design Goal & Scope

Idiographic design (ID) provides knowledge processes aim at producing knowledge that is both idiographic knowledge and design knowledge. In this case, the researcher seeks to use the design knowledge and methods to produce an ideal artifact from its CPPM design, which is intended for a specific problem (cost overrun and late delivery schedule).

3.3.2.2. Idiographic Design Nature of Knowledge

The knowledge role of an artifact is similar to genre of inquiry in both idiographic design (ID) and nomothetic design (ND). It embodies the design knowledge on the construction problematic (cost overrun, late deliveries, fragmented supply chain at job sites) either on a local context or globally.

3.3.2.3. Idiographic Design Quality Criteria

According to Baskerville *et al*. (2015), examples of criteria for idiographic design (ID) related to knowledge include a mix of the criteria for idiographic knowledge and idiographic design. These include satisfactory explanations that provides an understanding of the design and its settings, which require prolonged engagements, persistent observation, triangulation, or principles such as contextualization, dialogical reasoning, sensitivity to multiple interpretations, and suspicion (Goldstein *et al.,* 1978; Klein *et al*., 1999; Lincoln *et al*., 1985; Windelband *et al.*, 1980). Further criteria include the production of an acceptable similarity between expected and observed performance, inventiveness, innovativeness, and originality (Jones 2009; Martin 2009; Petroski 2009).

3.4. SCIENCE VIEWS OF DSR

For other researchers, science is paramount, with the primary products being valuable theories produced (Gregor *et al*., 2007; Walls *et al.* 1992). Theoretical goals often drive descriptive research, whereas pragmatic goals often drive prescriptive research. The science-centric view, on one hand will generally recognize knowledge as collective and shared, meeting with high standards of validity and/or reliability (Glanville, 1999). Being positivist in nature, the predominant criteria for finding the truth is based in its internal validity, whereas the criteria for the science neutrality leans on the science's objectivity or positivism (Lincoln *et al*., 1985).

3.4.1. Nomothetic Science

Nomothetic science (NS) can be particularly important in Design Science Research (DSR) when studying requirements for mass-market artifacts (e.g. software or apps) or studying the behaviors (Baskerville *et al*., 2015). An example of knowledge production for a nomothetic science (NS), it occurs when a researcher learns how a managerial problem at one job site do compare to other problems with other job sites for the same organisation. In the case of this thesis, this knowledge production for the nomothetic science (NS) was limited by conducting the research at only one construction site.

3.4.1.1. Nomothetic Science Goal & Scope

In nomothetic science (NS), knowledge processes will aim at producing knowledge that is both nomothetic and scientific. Researchers seek to develop generalized knowledge and generalized theories about natural or social settings and how these settings interact with classes of artifacts (Baskerville *et al*., 2015). In the case of this thesis, the researcher is not attempting to prove a specific theory based on this thesis' managerial problem. On the contrary, the researcher is trying to design an artifact or a model that will attenuate two managerial problems, which are subsequently supported by several kernel theories, as opposed to one theory in particular.

3.4.1.2. Nomothetic Science Nature of Knowledge

The role of generating knowledge in nomothetic science (NS) is to represent truth in a law-like way that has been proven or validated and the role of an artifact (the design itself). So, the objective of science being to deliver concrete validation (proof) of a desirable inner–outer environmental match across a pool of differing environments (e.g. construction sites across the world) will have to be pursue beyond this doctoral thesis. Therefore, although the CPPM design has been built with the association of kernels theories and observations, the researcher is unable at this time, to express a law-like affirmation based on the results obtain in this research.

3.4.1.3. Nomothetic Science Quality of Criteria

Like the nomothetic design (ND), examples of quality criteria for the nomothetic science (NS) include a mix of the criteria for nomothetic knowledge and scientific knowledge described earlier. These classic scientific criteria include applicability, generalizability, external validity, transferability, consistency, reliability, dependability, internal validity, and objectivity (Guba 1981; Lincoln *et al*., 1985).

3.4.2. Idiographic Science

Idiographic science (IS) is a systematic and validated study for a particular problem setting solve by a specific artifact (Baskerville *et al*., 2015). The role of idiographic science (IS) as a genre of inquiry cannot be overstated because the empirics in design-science research often revolve around a specific artifact (Baskerville *et al*., 2015). For example, when a design is seeking to learn about the nature of a given problem within a specific design context, the knowledge production is likely to involve idiographic science. The CPPM design was a true idiographic science (IS) study for its particular settings, however, the long term objective for the CPPM design is to be able to operate in a construction mass-market and to be able to study the environment (job sites) as a nomothetic science (NS).

3.4.2.1. Idiographic Science Goal & Scope

The goal of idiographic science (IS) is to examine the properties, functionality, utility, or effect of a specific artifact, and in a setting, such as in a construction mega-project. Evidently, these knowledge processes are aimed at producing an idiographic scientific (IS) knowledge for a short-term period. However, as stated above, the long-term endeavour of the researcher is to be able to control cost overruns and schedule delivery using the CPPM model, throughout several construction sites, making it more appealing to a nomothetic science view.

Because design settings are often unique in idiographic science (IS), like construction mega-projects, this genre of inquiry is validated by Simon's (1996) conceptualization of an artifact, where there is an interface between the unique inner environment or the organization of the artifact itself and the unique outer environment or the surroundings in which it operates.

3.4.2.2. Idiographic Science Nature of Knowledge

Idiographic scientific (IS) knowledge goes beyond establishing patterns of events; rather, it seeks to understand the underlying causes, structures, and generative mechanisms responsible for observed patterns (Tsoukas 1989). As global mega-projects are understood to be unique and limited in time, would global symptomatic problems such as cost overruns and late delivered have their own specific pattern? The researcher is questioning the potential reality that each statement is in fact, a global pattern, linked to the managerial problems of cost overruns and late delivered. For instance, the following patterns are investigated in Chapter Four:

- To interpret the relationships posited between the seven (7) construction constructs;
- To investigate the level of supply chain integration in an industry which is dominated by engineering and construction approaches;
- To investigate the level of supply chain robustness in regard to performance and productivity's metrics;
- To investigate performance attributes and metrics through semi-structured interviews and survey;
- Assess whether the nature of knowledge is supported by adequate internal validation.

3.4.2.3. Idiographic Science Quality Criteria

Examples of criteria for idiographic scientific (IS) include a mix of the criteria for idiographic and scientific knowledge described in the idiographic design (ID). These are satisfactory explanations that provide an understanding of the design and their settings, prolonged engagements, persistent observation, triangulation, or principles such as contextualization, dialogical reasoning, sensitivity to multiple interpretations, and suspicion (Goldstein *et al*., 1978; Klein *et al*., 1999; Lincoln *et al*., 985; Windelband *et al*., 1980). Other criteria include credibility and confirmability (Guba 1981; Lincoln *et al*., 1985).

3.5. KNOWLEDGE VIEWS OF DSR

The Design-Science Research process does not share the uniformity of a design study, nor does it share the uniformity of a scientific study (Baskerville *et al.,* 2015). For instance, during the Participant Observation (PA) and Action Research (AR), the researcher works as a designer and a researcher. The Design-Science Research (DSR) has similar duality: artifact development and knowledge production (Baskerville *et al.,* 2015); which is the centrality of knowledge production in DSR. Similarly, Simon (1996) points out the centrality of a knowledge production viewpoint in Design-Science Research has a dual mandate: (1) the utilization and application of knowledge for the creation of novel or innovative artifacts such has using the CPM or improvement in existing situations, and (2) the generation of new knowledge through the diffusion, for instance, of a doctoral thesis.

Different types of knowledge production occur through the reuse of past artifacts, creation of new ones, reflection about the design process or about the artifact, or even in design instruction (Cross, 2001). The artifacts generated in DSR can take several forms, including constructs, models, methods, and instantiations (March *et al*., 1995), design patterns (Gamma *et al*., 1995), design propositions (Romme, 2003), technological rules (van Aken 2004), design principles (Markus *et al*., 2002; Sein *et al.*, 2011), organizational designs and management practices (Niederman *et al.,* 2012), new properties of technical, social, and/or informational resources (Järvinen, 2007) and design theories (Gregor *et al*., 2007; Walls *et al*., 1992).

This thesis is in fact based on a timeline, with different episodic knowledge moments, with varying assumptions and methodical approaches. For instance, the researcher pursue different knowledge goals (economic benefits, inventory accuracy, supply chain optimisation, performance and productivity robustness) and applied different methodical approaches (Participant Observation and Action Research) and lastly conducted interviews and survey in order to finalize a model known as Construction Performance & Productivity Model.

Design-Science Research include both knowledge goals (design and science) and knowledge scope (idiographic and nomothetic). Recognizing and understanding the duality of design and science in DSR are useful for the analysis of design-science studies and the subsequent identification of appropriate criteria to apply during the justification and evaluation phases of this thesis.

3.5.1. Knowledge Paramount Views

The intent of using Design-Science Research is focus on its abstract (CPPM design) which produces knowledge in a construction setting. Therefore, instead of viewing a design just by its artifact and a theory with science, the knowledge-paramount view, reveals how the artifact is intertwined with both design and science, as well as how the theories are similarly intertwined.

Theory as an abstract entity is an intermeshed set of statements about relationships among constructs that aim to describes, explain, enhance understanding of, and, in some cases, predict the future (Gregor, 2006.) So, Design-Science Research contributes to knowledge and generalized theory (Gregor, 2006; Gregor *et al*., 2007; Hevner *et al*., 2004; Kuechler *et al*., 2012). Thus, the knowledge-paramount view clarifies issues concerning the role of theory and the artifact development which contribute to an evolving (kernel) theory. Gregor *et al*. (2013) express the view that contributions to knowledge could be a partial theory, incomplete theory, or even a generalisation in the form of an artifact.

This knowledge-paramount view, in agreement with this thesis, presents design-science as a rich, multifaceted paradigm in which the need for artifacts and theories do not simply coexist; rather, each proceeds from one to another (Baskerville *et al*., 2015). Knowledge production is enveloped in an iterative, constructive process that generates new knowledge that is sometimes quite specific to a designated context, but, at other time, highly abstract. Design relates to knowledge by creating a new world, whereas science studies the world to create new knowledge (Verkerke *et al*., 2013). Identifying a knowledge contribution is often difficult in Design-Science Research because the contributions to knowledge incremental artifact and/or partial theory building.

3.5.2. Knowledge Goals: Duality

Differing positions in these efforts promote tension between the goals of design versus the goals of science. The design-science activities, such as the design of the CPPM for this thesis, are associated with build-and-evaluate activities of a project lifecycle. The science activities of the CPPM are associated with justify-and-theorize activities (Hevner *et al*., 2004; March *et al*., 1995; Pries-Heje *et al*., 2014), and supported by kernel theories.

The CPPM design is a goal-driven activity which is focus in understanding why mega-projects are often over budget and delivered late. Hence, the CPPM aims at preventing the existing situations in construction mega-projects. It involves understanding the managerial problems that have plague the construction industry for more than fifty (50) years. Overall, the CPPM combines analytical modes of thinking with inventive modes to develop its design, whereas it can be applied throughout the project phases:

Conceptual, front-end planning, detailed engineering, construction and commissioning/turn-over.

Thus, the artefact (CPPM) is a design that takes for account the project flow process from the beginning to the end and is a very practical know-how that cannot be relegated down to a simple theory (Baskerville *et al.,* 2015). Contrary to this science-centric view, the proposed CPPM design, fits in the science of Management Information System (MIS), and such category of research rarely produce law-like explanations. MIS will rather produce explanations that are contextualized in human behaviour and contingent on carefully bonded ranges of philosophy and/or probabilistic claims of causality (Baskerville *et al.,* 2015).

The science-centric view, on the other hand, will generally recognize knowledge as collective and shared, meeting with high standards of validity and/or reliability (Glanville, 1999). Being positivist in nature, the predominant criteria for finding the truth is based in its internal validity, whereas the criteria for the science neutrality leans on the science's objectivity or positivism (Lincoln *et al*., 1985). In an opposing view, a constructivism approach based on its design, whereas the criteria for finding the truth is based on the design's credibility makes this approach neutral because of its confirmability (Guba, 1981).

The design-science duality represents the effort to establish rigor in information systems design-science studies (Baskerville *et al.,* 2015). For example, design methods and kernel theories that guide the design requirements and design process seek to formalize design-related knowledge (Walls *et a*l. 1992).

The design-science duality also highlights the importance of the design and science aspects of this research methodology. If one views design and science as a contradictive duality, these two elements appear instead as cooperating forces that, while still opposites, they are interdependent, intertwined, and reshaped by each other (Baskerville *et al.,* 2015). It helps emphasize the interdependence and softens the tension between the seemingly opposed nature of the knowledge goals of design and science, which are quite contrasting and somewhat contradictory (Baskerville *et al.,* 2015). For instances:

- Design knowledge goals are generative and inventive, although tempered by requirements and constraints;
- Scientific knowledge goals are conventional and systematic, although novel knowledge is sought.

Finally, the researcher for this thesis understand that experience and knowledge that can play a bias role, as in any knowledge-based activity. A challenge, then, is to accommodate and respect both the experiential knowledge of the researcher and the efforts to produce rigorous, justifiable knowledge (Baskerville *et al.,* 2015, Robillard, 1999). To counteract this bias role, senior managers at construction sites took part in evaluating the CPPM design, whereas the final design has been shaped by the respondents during interviews and survey.

3.5.3. Knowledge Scope: Nomothetic & Idiographic

As seen in the previous section, the knowledge goals with respect to science extends the existing knowledge into new knowledge. On the other hand, the knowledge scope in the Design-Science Research captures where the knowledge is applicable, to who it is accessible, and to whom activity it wishes to support (Baskerville *et al.*, 2015). Knowledge scope, then, involves a separate nomothetic–idiographic distinction which presents a duality that inhabits the creation of knowledge spanning the design-science duality.

According to Allport (1962), the philosophy in science uses the term *nomothetic* with respect to knowledge claims that consider a class of phenomena (laws) and *idiographic* with respect to knowledge claims that pertain to particular instances (i.e. structured patterns). The framework of DSR will often invokes both nomothetic and idiographic knowledge.

3.5.3.1. Nomothetic Knowledge Scope

Design-science researchers derive nomothetic knowledge through processes which involve abstract thinking. In fact, nomothetic knowledge production's processes do aim to produce general theories or concepts that cover the entire set of classes of a given problem. So, nomothetic claims tend toward reductionism in theories, valuing parsimony and limiting the number of constructs or variables in causal statements (Baskerville *et al*., 2015). The highest qualities in nomothetic knowledge are applicability, generalizability, external validity, transferability, consistency, reliability, and dependability (Guba, 1981). These criteria acknowledge that the knowledge should be useful, not just for a single phenomenon, but also for similar phenomena.

3.5.3.2. Idiographic Knowledge Scope

Idiographic knowledge production's processes tend to be local and are confined to particular cases or problems. For instance, idiographic knowledge involves the study of persons, social groups, or works of art (Bullock *et al*. 1988). Additionally, idiographic knowledge processes aim to produce specific concepts for the problem setting and its artifact. Therefore, idiographic claims tend toward contextualizing theories, valuing richness from larger numbers of constructs in causal statements, interviews, surveys, etc. (George *et a*l., 2005). Each artifact, in the CPPM design will have idiographic practical requirements that operationalise the general design theories under consideration.

In a DSR, a researcher derives idiographic knowledge through processes that involve practical thinking about a specific situation, such the managerial problems of this thesis. This mode of thinking involves deciding exactly how to solve this problem at hand, perhaps without regard to other settings or solutions (Baskerville *et al.,* 2015). Idiographic processes help the designer (researcher of this thesis) to think inventively about a unique situation (budget overruns and late deliveries of mega-projects) and to develop new knowledge, never encountered situations and solutions, such as the design of the Construction Performance & Productivity Model. According to Goldstein *et al*. (1978), idiographic knowledge is useful because the explanations and understanding penetrate the complexity of a problem, providing insights to reality, such as a construction site.

The phenomena are not repeatable with idiographic knowledge, so the quality criteria focus on how knowledge is distilled from the phenomenon. Lincoln *et al*. (1985) specifically recommend criteria that regard not just the knowledge itself, but also the methods of its production, such as prolonged engagements, persistent observation, and triangulation.

For this thesis, Design-Science Research has the dual challenge of solving a problem and creating a new knowledge. First, DSR attempts to solve the managerial problems of the construction industry, which is faced with poor performance and productivity for the past fifty (50+) plus years. The inefficiency effects cascade toward completing their projects most of the time over budget and associated with late deliveries. Second, the thesis design (CPPM) allows the DSR to create new knowledge, in this case, through the intermediary of a supply chain framework, within a project management culture that is typically engineering-driven up to the detailed engineering phase and construction-driven during the execution phase.

These different forms of knowledge production affect the goals of design and how an iterative process might, at one point, produce knowledge that is quite specific to the research environment (design) context, at another point, produce quite abstract knowledge such as theorising (Baskerville *et al.*, 2015).

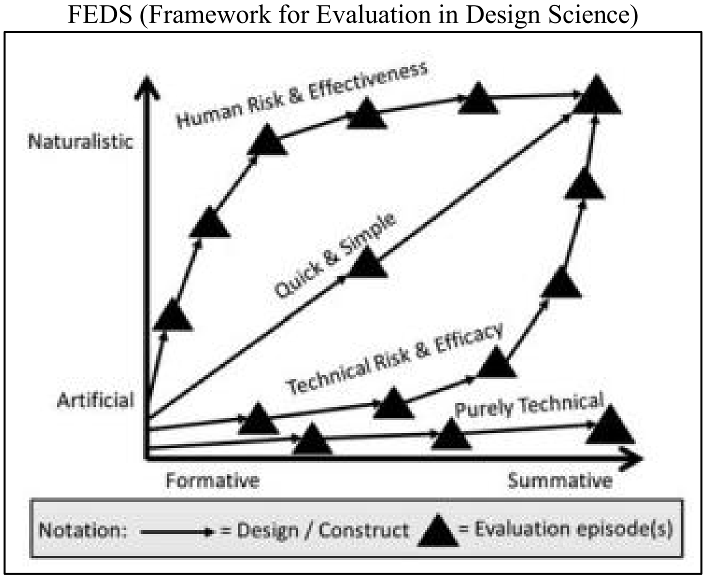
Hence, the duality of knowledge goal and scope involves in this research is essential in the centrality of the knowledge production and explain the ontology approach of the constructivism and pluralism for this thesis. Finally, this thesis adopts the notion of duality as being essential and it is based on the notion of duality taken from Giddens'

Structuration Theory (Giddens, 1979; Giddens, 1984) where duality identifies two conceptually different elements as interdependent and longer separable.

3.6. EVALUATION STRATEGIES

Design-Science Research differs from other researches and gives rise to different evaluation strategies. Each strategy implies a decision about why, when, and how to evaluate. The priority of the artefact design is to fulfil a need to solve the two managerial problems that have persisted over fifty (50+) plus years in the construction mega-projects: cost overruns and late scheduled deliveries. According to Vendable *et al*. (2016), each strategy in DSR operates as a progression that proceeds from the origin of the formative to summative and artificial to naturalistic evaluations. Figure 3.5 and Table 3.1 demonstrate four potential strategies to evaluate a Design Science Research. These strategies include: (1) Human Risk & Effectiveness; (2) Quick & Simple; (3) Technical Risk & Efficacy; and (4) Purely Technical Artifact.

Figure 3. 5
FEDS (Framework for Evaluation in Design Science)



Vendable *et al*. (2016)

Table 3. 1
DSR Evaluation Strategies

DSR evaluation strategies	*Circumstance selection criteria*
Quick & Simple	If small and simple construction of design, with low social and technical risk and uncertainty
Human Risk & Effectiveness	If the major design risk is social or user oriented *and/or* If it is relatively cheap to evaluate with real users in their real context *and/or* If a critical goal of the evaluation is to rigorously establish that the utility/benefit will continue in real situations and over the long run
Technical Risk & Efficacy	If the major design risk is technically oriented *and/or* If it is prohibitively expensive to evaluate with real users and real systems in the real setting and/or If a critical goal of the evaluation is to rigorously establish that the utility/benefit is due to the artefact, not something else
Purely Technical Artefact	If artefact is purely technical (no social aspects) or artefact use will be well in future and not today

Vendable *et al*. (2016)

3.6.1. Human Risk & Effectiveness Evaluation Strategy

The evaluation strategy opted for the CPPM design is primarily the Human Risk & Effectiveness Evaluation Strategy. This strategy emphasises formative evaluations early in the process, but quickly move to a more naturalistic formative evaluations near the end of the research. Hence, near the end, the strategy of summative evaluation is engaged, and a rigorous evaluation of the effectiveness of the artifact commence. For instance, validation of the CPPM design is made through interviews, survey, qualitative statement and quantitative analysis. The objective of moving from formative to summative and naturalistic evaluations are for the benefits of the artifacts, which are placed in construction situations.

Therefore, the Human Risk & Effectiveness evaluation strategy is most appropriate for socio-technical artifacts such in the activities of construction mega-projects, which have major social and economic uncertainties. The Human Risk & Effectiveness evaluation strategy also have with a strong need to rigorously establish long-term effectiveness in real life environment settings. Once again, the evaluation of the artifact (e.g. CPPM) is located in a naturalistic environment (job site), conceived for real life organisation (construction industry), and are facing real problems (cost overruns and late schedule deliveries during mega-projects).

The increasing use of more summative evaluation as the research progresses*,* enables comparison of research outcomes with research expectations (testing the design theory – which is not the case for the CPPM design). For the y-axis, the artificial evaluation used in a more positivist approach is not considered for this thesis. The artificial evaluation is, where validation includes laboratory experiments, simulations, criteria-based analysis, theoretical arguments, and mathematical proofs (Venable *et al*., 2016). The next three strategies that are described in Vendable *et al.* (2016) were not preferred in this research, however, in terms of contents, it is essential to describe them.

3.6.2. Quick & Simple Evaluation Strategy

The Quick & Simple Evaluation Strategy conducts relatively little formative evaluation and progresses quickly to summative and more naturalistic evaluations. This strategy includes relatively few evaluation episodes (perhaps even only one summative evaluation at the end). Such a strategy is low cost and encourages a quick project conclusion. This type of quick evaluation in a very complex environment such as construction sites would not be held much respect in the industry.

In the case of this thesis, the episodic pathways which the research took over seven (7) years, starting with the Participant Observation at the engineering firm (formative + naturalistic), then conducting an Action Research (formative + naturalistic) at a construction site, and finally concluding with a Design-Science Research (summative

+ naturalistic) supported by constructs, semi-structured interviews and survey. This episodic pathway is hardly short in time, as prescribed in the Quick & Simple Strategy.

3.6.3. Technical Risk & Efficacy Evaluation Strategy

The Technical Risk & Efficacy Evaluation Strategy falls under a purist positivism approach, which emphasises artificial and formative evaluations iteratively early in the process, but progressively moving towards summative and artificial evaluations. Although lots of mathematical models are presented in construction management, the artificial or laboratory vision of the Technical Risk & Efficacy Evaluation Strategy does not appeal to the CPPM design, which emphasizes a real-time environment.

3.6.4. Purely Technical Evaluation Strategy

The fourth strategy known as Purely Technical Evaluation Strategy is used when an artifact is purely technical, without human users, and make naturalistic evaluation irrelevant. Obviously, this strategy, like the Quick & Simple Strategy, favours an artificial evaluation over naturalistic one, and doesn't fit with the CPPM design, falling once again, in the category of naturalistic evaluation.

3.7. EVALUATION PROCESSES OF THE DESIGN-SCIENCE RESEARCH

The difficulty with validating the DSR arises from a combination of factors, which include the relative youth of the information technology disciplines, and the comparatively recent recognition of DSR as a distinct, yet legitimate research paradigm (Gregor et *al.*, 2013). Henceforth, Gregor (2006) sets forth a taxonomy of five (5) different types of theory in use within the field of Management Information System (MIS or IS): a) for analysing, b) for explaining, c) for predicting, d) for explaining and e) for predicting.

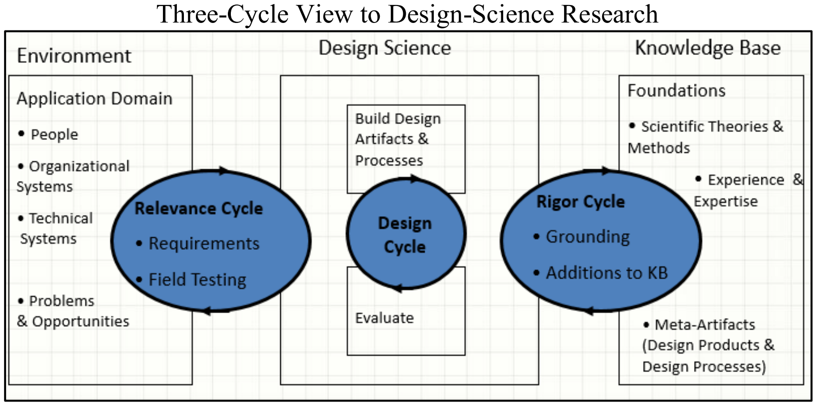
In Design-Science Research, the research process frequently faces hurdles between the development and the evaluation phases (Kuechler *et al*., 2005). The experimental settings are by default, very complex due to the need of in real-life environment. As described in previous sections, the relationship of an artifact to its related kernel theories is an extension and refinement of several theories into a mid-range theory, rather than a disconfirmation of a theory per se (Caroll *et al*., 1989).

On the opposite side of science, natural and behavioural experiments take place in much more restricted environments that those of DSR. In fact, a research in natural science, which are theory-driven, is ideally constructed with clear interpretation of the results, and the theory is eventually either supported or disconfirmed. Hence, the nature of Design-Science Research makes it unlikely that a theory from natural or behavioural science will be readily adaptable in a mega-project environment.

3.7.1. DSR Lifecycles

Previously mentioned, the evolution of Design-Science Research is episodic in itself. Hevner (2007) offers three (3) cycle views to Design-Science Research which are demonstrated in Figure 3.6. First, there is the relevance cycle, followed by the design cycle and at last, the rigor cycle.

Figure 3. 6
Three-Cycle View to Design-Science Research



Hevner (2007)

3.7.1.1. Relevance Cycle

Relevance cycle is the application domain which initiates DSR with the research requirement such as the managerial problems during mega-projects. Then, the acceptance criteria for evaluation of the design artifact in the application domain will be field tested as to understand if the artifact, in this case, the thesis model, will improve the construction industry in controlling the managerial problems. The researcher will also want to know how the improvement is being measured during the relevance cycle.

Initially, the researcher investigated the economic effects on the construction industry versus its poor labour performance and productivities; through the lenses of the Resources-Based View. Field testing methods were then initiated by a Participant Observation in an engineering firm, followed by an Action Research at a construction site during a mega-project located in the Province of Saskatchewan. The last part of testing was made by administering a series of semi-structured interviews and survey. The relevance cycle continued for three (3) years at a construction site.

The cyclical nature of DSR's processes may demand different episodic evaluations at different stages of progress. This thesis is no different to the path of which a Design Science Research follows throughout its three cycles. It became obvious that most of the projects the researcher took part in, they were suffering negative economic effects. These negative economic effects affected directly the owners' financial reporting

3.7.1.2. Design Cycle

The design cycle for this research started with the Design-Science Research. The accumulation of seven (7) years of participant observation, action research, constructs, data, interviews and survey permitted the researcher to design the Construction Performance and Productivity Model geared toward mega-projects. The researcher created and refined its design as both an artifact and a series of processes. The design itself is used to understand the managerial problems, which evolved in complex interactions, dependent on human cognitive abilities (creativity) and human social abilities (teamwork). Fortunately, the researcher has had the inherent flexibility to change the design and its processes over the span of the research period. Notwithstanding the inherent flexibility to change, the researcher committed itself to a rigorous design and scientific study of its artifact in conjunction with the mega-project. Part of the design cycle was the selection of the kernels theories, related to construction management and management information systems. The researcher believes, as it is demonstrated in Chapter Four (Results) the artifact provided a new knowledge base (KB) for construction management and management information systems.

3.7.1.3. Rigor Cycle

The rigor of the Design-Science Research is based on Knowledge Base (KB), which is reinforced by experiences and expertise from the researcher, including previous and new experiences, expertise in supply chain and construction management, through observing constructs, taking part in a participant observations and an action research, and finally conducting a series of semi-structured interviews and survey. On the theorical side, the researcher selected several kernel theories as its mid-range theory. The rigor of the design and its theories are expected to make a useful knowledge contribution in the construction industry. The reader, however, must note the artifact has an epistemological limitation, due to the subjectivity of the researcher toward supply chain approaches and their known benefits in manufacturing. The artifact has also been tested at only one construction site. The research limitations are discussed in more details under Chapter Four.

3.7.2. Seven Evaluation Guidelines

Hevner *et al.,* (2005) and Peffers *et al*. (2008) have presented a set of guidelines for proceeding to a successful DSR methodology and supported by rigorous results. According to the authors, Design-Science is based on management information system' methodology which offers seven (7) specific guidelines for evaluation and iteration of a research project, such as this doctoral thesis. The objectives of a DSR are to develop knowledge and understanding of a problem domain by building an application through a design artifact. The DSR guidelines are the following:

1. Design as an Artifact: DSR must produce a viable artifact in the form of a construct, a model, a method or an instantiation. For this first guideline, a Construction Performance & Productivity Model has been developed in Chapter Four;

2. Problem Relevance: The objective of a DSR is to develop technology-based solutions and used to solve relevant business problems. For this second guideline, the artifact is designed with the objectives of selecting the right attributes and metrics in order to attenuate projects' over budget and late deliveries;

3. Design Evaluation: The utility, quality and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods. For this third guideline, a model based on SCOR has been modified in order to cover all phase aspects of construction project management;

4. Research Contributions: Effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies. For this fourth guideline, the final model was tested for its flexibility in meeting four (4) types of construction contracts;

5. Research Rigor: DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artifact. This fifth guideline is expressed above. Rigor is supported by previous and new experiences and expertise, by observing constructs, conducting a participant observations, an action research, a series of semi-structured interviews and survey, and finally, by kernel theories along with a mid-range theory;

6. Design as a Search Process: The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in problem environment. For this sixth guideline, laws are not sought to be proven, and construction sites are not an immune laboratory, but rather a complex environment with various stakeholders pushing for their interests.

7. Communication of Research: In order to be effective, DSR must be presented effectively both to technology-oriented as well as management-oriented audiences. These preliminary results have been presented at the ACFAS, in May 2019.

In summary, the artefact's design understands the need to have a relevance cycle, supported by a design cycle and a scientific rigor. The three cycles enumerated above are a support for DSR's internal validation through its artifact. The next section will detail three forms of evaluations:

1. Formative Evaluation: conducted early in the research through a Participant Observation and an Action Research;
2. Summative Evaluation: conducted near the end of the research through interviews and survey;
3. Naturalistic Evaluation: real-life settings are costly, time sensitive and accessibility to a construction site are to obtain. However, the researcher had the privilege to work at senior management level in various construction sites;
4. Artificial Evaluation.

3.7.3. Formative Evaluation

According to Venable *et al*. (2016), formative evaluations are used to produce empirically based interpretations that provide a basis for successful action in improving the characteristics or performance of the environmental settings. Moreover, the formative evaluation, in terms of time, can also be performed ex-ante, in order to estimate and evaluate the impact of future situations (Stefanou, 2001).

Formative evaluation is particularly important when design uncertainties are significant and is a way to reduce risk due to design uncertainties (Vendable *et al*., 2016). In this research, the environmental settings are obviously the construction mega-projects. The formative methodologies selected in this research were a Participant Observation and an Action Research. Formative evaluations focus on consequences and support the kinds of decisions that intend to improve the environmental settings (William *et al*., 1996). Hence, the eventual objective of validating if the CPPM works, is to use the design as a tool to improve the measurement of the performance and productivity during construction mega-projects, with the confidence to prevent cost overruns and late deliveries for mega-projects.

3.7.4. Summative Evaluation

Venable *et al*. (2016) described summative evaluation as being used to produce empirically based interpretations (i.e. metrics and analytics) that provides a basis for creating shared meanings (i.e. labour, equipment and material costs and schedule control) within the environmental settings such as construction mega-projects (William *et al*., 1996).

This distinction arises from the timing of the evaluation episodes. The episodes of formative evaluations are often regarded as iterative or cyclical (William *et al*., 1996) and measure improvement as development progresses. For instance, the progress through learning and evaluating with methodology of an Action Research is a form of formative evaluation. Summative evaluation episodes, on the other hand, are used to measure the results of a completed development or to appraise a situation before development begins (Venable *et al*.; 2016). For instance, the measurement of performance and productivity with the thesis' design is a form of summative evaluation.

In this thesis, the summative approach of the researcher was not focus on trying to decipher the complexity of the construction industry as an entity, but improve the performance and productivity of mega-projects, in an attempt to control cost overruns, schedule deliveries and investigate if the integration of supply chain processes into construction is possible.

Finally, the functional purpose of summative evaluation is to judge the extent that the outcomes match expectations. For example, certification, progress, or even the effectiveness of the process itself is a form of summative evaluation (William *et al*., 1996). In addition, the summative evaluation is measured in terms of timing as a post evaluation (Klecun *et al*., 2005). Science also presents ex-post evaluation, which regards a chosen system or technology, after it has been acquired, designed, constructed, or implemented in an environmental setting. Presenting an ex-post evaluation is not an objective for this doctoral thesis.

3.7.5. Naturalistic Evaluation

As pointed out by Venable *et al.* (2016), naturalistic evaluation methods typically include case studies, field studies, field experiments, survey, ethnography, phenomenology, hermeneutic methods, and action research. When performing a naturalistic evaluation*,* the researcher explores in its real environmental setting (e.g. construction site), the performance of a solution technology, a system or model (e.g. CPPM design). By performing evaluation in a real environment, a naturalistic evaluation embraces all the complexities of human practice in real life (Sun *et al*., 2006) and must disentangle the effects of many confounding variables in those environmental settings.

Moreover, the validation of the CPPM design through a naturalistic evaluation will naturally tend towards interpretivist and subjectivism, along with some positivist. Nonetheless, the dominant interpretive paradigm of naturalistic evaluation brings the benefits of stronger internal validity (Gummesson, 1988).

3.7.6. Artificial Evaluation

To the extent that an artificial evaluation are not real-life settings, but more like laboratories, results will most often not correspond to real application settings like a mega-project. This research reiterates the importance for the CPPM design to be construction friendly and be environmentally applicable.

Although the evaluation type for the CPPM design is a pure naturalistic, this thesis considers the importance of discussing the paradox view to naturalistic view, which is the artificial evaluation. First, an artificial evaluation may be empirical or non-empirical (e.g., logical/rhetorical). Second, the epistemological results are most often positivist and reductionist, and are being used to test design hypotheses (Walls *et al*, 1992). Third, artificial evaluations include laboratory experiments, simulations, criteria-based analysis, theoretical arguments, and mathematical proofs (Venable *et al*., 2016). Fourth, artificial evaluations are less susceptible to misinterpretation and bias. Finally, an artificial evaluation would tend to favor the science part of the Design-Science Research approach and it brings the benefits of stronger scientific reliability in the form of better repeatability and falsifiability (Gummesson, 1988).

Hence, the utilisation of an artificial evaluation will not be a methodology employed by the researcher, especially since the researcher's approach was to distance itself from the current literatures, which offer theoretically-centered researches that are less if not, non-practical to the views of construction stakeholders.

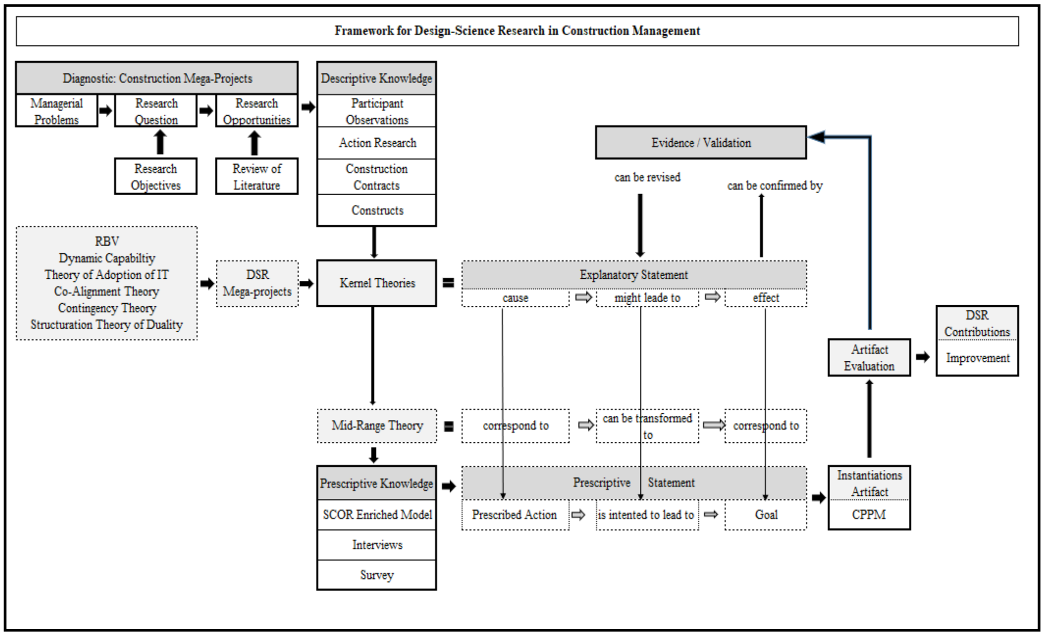
3.8. OPERATIVE FRAMEWORK

3.8.1. Research Framework

The research framework provided by the Design-Science Research approach is presented in Figure 3.7. This thesis recognizes the contribution of both designs and kernel theories in making true the methodology of Design-Science Research. Design-Science Research addresses important real-world managerial problem in unique or innovative ways, making a clear contribution to the real-world application environment from which the research (doctoral thesis) problems are drawn from (construction mega-project).

Conducting a design-only or theory-only research is not suitable to research as either one contributes to knowledge. Journals like MIS Quarterly impose a clear theoretical contribution from research articles with empirical findings or a detailed description of an artifact (Gregor *et al*. 2103). The kernel theories expressed in the previous chapter, different by themselves, will explain in part, why and how the design artifact work for this research.

Figure 3. 7
Thesis Framework for DSR in Construction Management



Dany Julien (2019)

The researcher was able to use the flexibility of the DSR framework and transferred its research from a theoretical standpoint to a practical one. For instance, the researcher began, at studying the environment where the managerial problems occurred, established the research question and objectives, reviewed literature and pinpointed research opportunities. Hence, this first part of the research was in essence, a diagnostic to the mega-projects' problems.

The researcher, then brought its theoretical (diagnostic) knowledge onto the practical side of DSR, where a descriptive knowledge would be established by conducting two residencies. The first residency, through a Participant Observation methodology was used to validate the amount of supply chain activities during the phases of construction mega-projects. The second residency, through an Action Research methodology, was selected in order to validate the inventory accuracies at a mine project. The conclusion of these two descriptive residencies was translated by naming seven (7) constructs and four (4) types of construction contracts.

The third step for the researcher was to go back on the theoretical side and explored various kernels theories through a second review of literature. The end-results of these findings resulted in the decision to use the SCOR Model as the base of the operational framework for the artefact. However, too focus on manufacturing's supply chain processes, the SCOR Model was enriched with performance attributes and KPIs related to all phases of construction project management.

Once the SCOR Model had been enriched, the next objective of the research was to reduce the amount attributes and metrics, so that the final artefact (CPPM) became less cumbersome to the field users and in parallel, met the objectives of this research. Thus, the SCOR enriched model went through a series of semi-structured interviews and one survey, to eventually be formulated into the Construction Performance & Productivity Model (CPPM). The next sections describe the DSR framework in more details.

3.8.2. Research Workplace

The researcher spent four (4) years (2011-2014) working at the world's second largest EPCM engineering firm and was employed in its Mining & Metals division. While employed with this firm, the researcher assumed the role of Transportation & Logistics Manager within its Procurement Department. During these years, the researcher took part in several pre-feasibilities (conceptual, front-end planning) and feasibilities (detailed engineering) studies as well as executing construction projects.

While observing the current managerial problems, where projects were commonly completed over budgets and being delivered late, the researcher decided to investigate (Participant Observation: 2013-2014) during the last two (2) years of employment, the paths of project flow and the amount of supply chain activities during mega-projects. The review of these paths was an attempt to understand, first, the root and cause to the managerial problems, and second, to measure the amount of supply chain metrics, used in the activities of project management. The researcher also spent in parallel works, two (2) years at various construction sites (2013-2014), including projects in iron ore mining, bauxite and rare earth minerals. While affected at these sites, the researcher assumed the position of Material Manager.

Following his corporate assignment with the EPCM firm, the researcher changed employer and moved on with a Construction Management Team (CMT) company. There, the researcher worked in a green / brown project (2014-2017) where a uranium mill was upgrade and underway. By the time the researcher mobilized at the construction site in northern Saskatchewan, approximately 60% of the mill upgrade had already been procured for the project. During this period, the researcher worked under the functionality of the Owner's CMT and acted primarily as the Transport/Material/Procurement Manager at site. Near the end of the project (2016-2017), the researcher eventually took secondary assignments as Lead Planner and Site Services Lead.

While employed at the mill upgrade, the researcher conducted an Action Research (2015-2016) where inventory accuracies were audited against two Prime Contractors. Then upon completing the mill upgrade assignment and returning home (2017), the researcher started the interviews and survey to finally analyse over one and half year (2017-2018).

As a result, the knowledge production varied in time as the research evolved from two residencies, two reviews of literature, and sets of interviews and one survey. The methodology of DSR became a unique paradigm by itself, with modes of inquiries such as positivism, interpretivism, constructivism, etc. (Iivari 2007). It is important to visualize DSR as episodic knowledge moments in different genres of inquiry, since the method of analyzing, justifying, evaluating, and articulating the contributions of the Participant Observation, Action Research and the interviews and survey were used to construct the artifact (Construction Performance & Productivity Model).

In terms of its academic progress, the researcher conducted its doctorate classes on a part-time basis between 2011 and 2014. While living at a construction site (2014-2017), the researcher had the opportunity to draft the *Review of Literature* (DBA 960), followed by a *Research Proposal* (DBA 970), and the data collection and analysis for its *Doctoral Thesis* (DBA 980).

With respect to the workplace, the mill upgrade project in June 2013 was evaluated at $85M, and when construction began, approximately 40% of the detailed engineering had been completed and ready for construction. By the end of 2014, the owner's project had expanded its scope of works with more additional areas being built. The budget was then increased to $213M. Once completed in 2017, the mill upgrade had costed nearly $333M.

3.8.3. Participants in DSR

The type of participants which took part in various methodologies during this thesis research differ in many characteristics, such as by their types of employment, ages, experiences, job positions and types of companies they worked for. Participants (i.e. engineers) were observed during the Participant Observation over the project flow activities; the Action Research (i.e. Prime Contractors) intended to control inventory management, and the semi-structured interviews and survey of the Construction Production & Performance were analysed in order to construct the final design (abstract) for the upcoming CPPM.

Using Spradley (1980) types of participant observations, the observer (researcher) categorises himself as a Complete Participation. Spradley (1980) described in more details five (5) types of participant observations, and they are summarised below under Table 3.2.

Table 3. 2
Types of Participant Observations

Type of Participant Observation	Level of Involvement	Limitations
Non-Participatory	No contact with population or field of study.	Unable to build rapport or ask questions as new information comes up (Dewalt *et al*., 1998; Schwartz et al., 1995).
Passive Participation	Researcher is only in the bystander role.	Limits ability to establish rapport and immersing oneself in the field (Dewalt *et al*., 1998; Schwartz et al., 1995; Spradley, 1980).
Moderate Participation	Researcher maintains a balance between "insider" and "outsider" roles.	Allows a good combination of involvement and necessary detachment to remain objective (Dewalt *et al*., 1998; Schwartz et al., 1995).
Active Participation	Researcher becomes a member of the group by fully embracing skills and customs for the sake of complete comprehension.	This method permits the researcher to become more involved in the population. There is a risk of "going native" as the researcher strives for an in-depth understanding of the population studied (Dewalt *et al*., 1998; Schwartz et al., 1995; Spradley, 1980).
Complete Participation	Researcher is completely integrated in population of study beforehand (i.e. he or she is already a member of particular population studied).	There is the risk of losing all levels of objectivity, thus risking what is analyzed and presented to the public (Dewalt *et al*., 1998; Schwartz et al., 1995; Spradley, 1980).

Spradley, 1980

Expanding on Spradley (1980) types of participant observations, Gold (1958) provides a description of four (4) observation stances, which described the degree to which a researcher involves itself in participating in the culture under study.

1. Complete Observer: The observing stance was preconized by the researcher during the Participant Observation methodology. During this observation period, the researcher didn't study himself and was completely hidden from his co-workers while working with them at the engineering firm, during the detailed engineering and construction phases. The observation was unobtrusive and unknown to participants. The researcher noted though, the Vice-President of Procurement, which the objective of the research was for studying the amount of supply chain integration.

   However, due to the subjectivity of human cognitive thinking, the researcher is aware of the disadvantages of this stance as the researcher may lack objectivity, such as having expressed organisational questions toward the engineering-driven and construction-driven cultures that drive project management today.

   On the other hand, engineers are so driven in solving design problems and for their parts, construction specialists are also driven in solving day-to-day problems, that having the researcher's role revealed during the period of observation was never a concern. In fact, the researcher believes the engineers and construction specialists would not have paid attention to the idea of having a supply-chain-driven project, being themselves center-focus in their silo environment;

2. Complete Participant: In this case, the researcher is a member of the group being studied and who has concealed his/her researcher role from the group to avoid disrupting normal activity. Contrary to the Complete Observer above, the researcher in the Complete Participant is also a member of the group that is being studied amongst his/her co-workers. This observation techniques did not apply for this research;

3. Participant Observer: Here, the researcher is a member of the group being studied, and the group is aware of the research activity. In this stance, the researcher is a participant in the group who is observing others and who is interested more in observing than in participating, as his/her participation is a given, since he/she is a member of the group. This role also has disadvantages, in that there is a trade-off between the depth of the data revealed to the researcher and the level of confidentiality provided to the group for the information they provide. This observation techniques did not apply for this research;

4. Observer as Participant: During the thesis' Action Research, the Observer as Participant was utilised whereas the researcher was a member of the Construction Management and enables him (the researcher) to participate in the group activities with the Prime Contractor's Planning Team.

   The Prime Contractor's Planning Team being studied was aware of the researcher's observation activities. In this stance, the researcher was an observer who was not a member of the Prime Contractor's Planning Team, but whom was interested in participating as a means for conducting better observations and, hence, generating more complete understanding of the Prime Contractor activities.

3.8.4. Managerial Problems

The construction industry is often criticized for delivering projects late and over budget. According to Changali *et al. (2015)* of McKinsey & Co., 98% of mega-projects suffer cost overruns and more than 77% of the mega-projects are at least 40% late from their original schedules. The lists of reasons why mega-projects suffer costs overruns and late deliveries are exhaustive. Hence, the construction industry, especially during mega-project, is plagued by the symptomatic managerial problems of why cost overruns exist and projects are being delivered late.

3.8.5. Research Question

The researcher understands they are various reasons and solutions linked to the problematics of cost overruns and late deliveries during construction mega-projects. So, the integration of supply chain processes within the framework of construction project management is proposed in this thesis as one of many potentials solutions that may help decreasing the managerial problems.

Through observations, participations, action research, and semi-structured interviews, survey as well as applying several kernels theories, the researcher developed an artifact (design), titled the Construction Performance & Productivity Model (CPPM), which attempts to integrate supply chain processes, performance attributes and metrics into the activities of construction project management. These activities include procurement, engineering, construction, cost controls, worker management as well as project complexity (off and onsite). In order to validate the value of this proposed artifact, the researcher put forward the following research question into two sections:

- While integrating a supply chain framework processes (end-to-end) in construction project management, which performance attributes and metrics are essential to a model having the objective of attenuating the managerial problems of cost overruns and late deliveries, while considering four (4) types of construction contracts?

- Subsequently, in this proposed supply chain-driven model, is there a certain dominance of performance attributes and metrics belonging more to engineering, procurement or construction activities?

3.8.6. Research Opportunities

Technological journals, periodicals, textbooks, etc. all agree that there are systemic problems in the construction industry regarding performance and productivity. Construction is said to lag the business sector as a whole and in particular, the manufacturing sector. The researcher considers more studies could be engaged in measuring manufacturing build processes versus construction build process.

There is a growing literature body of construction management which draws on ethnographic methods to help better understand the lived experiences and practices of people in project setting (Baarts, 2009; Shipton *et al.,* 2014; Theil, 2013). The researcher believes there is a need for more in-house researchers, when studying mega-projects.

Literatures and technical journals offer several approaches that can partially solve this managerial problematic. The researcher came across very few articles that considered the benefits of automation and management information systems which were implemented in real-live projects. Thus, automation and management information systems involve in construction management offer good research opportunities.

Finally, the researcher with a doubt, considers that construction analytics must be investigated in more details and applied in various job sites. Big Data, data warehousing and data management are under-exploited, if not inexistent, in construction management. Construction analytics offers tremendous amount of research opportunities.

The Construction Performance & Productivity Model (CPPM), which is presented in this thesis evolves from borrowing some of the attributes and metrics of the SCOR (Supply Chain Operations Reference) Model, published by the Council of Supply Chain (USA). Understanding the main audience for the SCOR Model is the manufacturing sector, the researchers with twenty (20+) plus years in supply chain and construction experience, has modified the original model into one that meet the constraints, challenges and complexities of engineering and construction during mega-projects. Thus, this model is one solution in the sea of construction problems, which are present during mega-projects. This model offers an opportunity to look at construction activities with supply chain lenses. Once again, the researcher reiterates the CPPM design is not holistic, however, this model is one out of many solutions, and offers good research opportunity.

3.8.7. Residency no.1: Participant Observation

Participation Observation originates from ethnographic research, where researchers were living in tribal cultures. Like tribes, or a series of tribes, union trades and construction organizations, have various traditions, customs and cultures (Vinten, 1994). Participant Observation is also an approach which is grounded in a commitment to the first-hand experience and exploration of a particular social or cultural setting, such as the construction industry (Atkinson *et* al., 2001; Kemmis *et al*., 2004). In Participation Observation, the researcher can become actively involved in the situation being studied, participating overtly or covertly for an extended period of time (Hammersley *et al.*, 1995; Denzin *et al.*, 2005).

So why the researcher selected the methodology of Participation Observation for its research? Participant Observation entails understanding a wide range of aspects which make up social life, for example, stakeholders' motives, power asymmetries between stakeholders, patterns of miss-communication caused be the lack of transparencies amongst sub-contractors, and so forth (Cicmil *et al*., 2006). Hence, Participation Observation for this research focuses on real life settings, not artificial environments, nor laboratory environment created by researchers. So, Participant Observation truly allowed the researcher to gain insights knowledge of construction mega-projects.

For its first residency and validation of the managerial problems, the researcher took the advantage of its position (Transportation & Logistics Manager) over a period of four (4) years at an engineering office (August 2011 to May 2014) and at a construction site (May 2014 to December 2014).

The Participant Observation by itself, however, took place between 2013-2014. This observation period allowed the observer (researcher) to obtain more details and accurate information about project processes involving individuals, stakeholders, companies and tradesmen that were part of the mega-project. As it is described in Howell's works (1972), the observer (researcher) was able to establish a rapport by getting to know the senior managers assigned to various mining projects and taking part in the execution of the several plans, including Construction Execution Plan, Procurement Execution Plan and Logistics Execution Plan.

The objective of understanding the underlying activity flows during a construction project was to evaluate the amount of supply chain metrics that were used by an EPCM firm. Thus, in order to understand the activity flows of construction project management, the observer (researcher) reviewed first, the flows of project activities pertaining to several school of thinking, and second, recorded and build along side a team of various senior engineering, procurement and construction staff, a process flow of project management activities. The school of thinking employed in this research are the following:

1. Project Management Body of Knowledge (PMBOK). It is a standard guide that is internationally recognized (IEE STD: 1490-2003), of which it provides the fundamentals of project management, as they apply to a wide range of projects including construction, software, engineering, automation, etc. The main body is known as PMI (Project Management Institute). Appendix A covers the different cycles of PMBOK.

2. Construction Industry Institute (CII). This is the body of the American construction companies and has a strong hold in southern USA with the O&G industries. Appendix B covers the different cycles of CII's project management;

3. Construction Owner Association of Alberta (COAA). Similar to the CII, this association represents primarily the large companies working in the oil sand business; Appendix B covers the different cycles of COAA's project management;

4. Value Reference Model (VRM). It is a conceptual model made popular by Michael Porter. It has been widely adopted by the business community as a mechanism to understand and comprehend complexity in business environments, with the goal of structuring the business to maximize its competitive advantage (van Resburg, 2006);

5. Project In Controlled Environments (PRINCE2): It is used extensively by the UK government as a process-based approach for project management providing an easily tailored and scalable method for the management of all types of projects. Key features of PRINCE2 are described on its web page (www.prince2.com): (1) focus on business justification, (2) defined organisation structure for the project management team, (3) product-based planning approach, (4) emphasis on dividing the project into manageable and controllable stages, (5) flexibility that can be applied at a level appropriate to the project;

6. Canadian Construction Association (CCA). This association represents Canadian contractors across the country. It has a similar function to the CII in the USA;

7. The Construction Institute of Canada (TCIC). The TCIC is a continuing professional development institute in Canada with the mission to develop and sustain the highest level of professionalism for the construction industry practitioners.

Once the various bodies of knowledge stated above were thoroughly analyzed and understood, the Participant Observation methodology allowed the researcher to observe and participate in project procedures from the conceptual phase to the front-end planning and detailed engineering and simultaneously at a construction site where an iron mine was being built in a remote sub-arctic region.

During this period, the researcher measured the level of supply chain implementation in project management activities, as well as the standing barriers that prevented such an end-to-end implementation. The researcher was able to experience the meanings and interactions of the various construction stakeholders (owner, contractors, engineers, unions, CMT) from the role of an insider living with them every day. It enabled the researcher to place specific encounters, events and understandings into fuller, more meaningful context (Jorgensen, 1989; Tedlock, 2000). The researcher recorded data, observing freely, and consolidating the information gathered into his final observation work called Project Flow Analysis (Appendix E2, Chapter Four – Result). The observations during the four (4) year-period involved a range of well-defined methods. For instance, there were (1) informal interviews with senior manager in engineering, construction and procurement; (2) comparative observations of project management activities versus current body of knowledge; (3) participation in a real-life settings in engineering, construction and procurement groups; and (4) results from technical articles and research literatures, and personnel experience.

Thus, the Project Flow Analysis starts at analyzing (1) the Conceptual phase of a project, (2) following through with the Front-End Planning, (3) Detailed Engineering, and (4) construction. The project phases are described below:

1. Initiating (Conceptual Phase): This stage defines and authorizes the project. Generally, the project is named, a Work Breakdown Structure (WBS) is established with specific area of works. The project manager is named, and the project charter is created by containing items such as the purpose of the project, a high-level product description, assumptions and constraints, a summary of milestone schedule, and a business case for the project. A preliminary scope statement is also established during the Initiating Phase. Similarly, in construction mega-projects, the Conceptual Phase in name, replaces the Initiating Phase. The cost order of magnitude for the expected accuracy range is limited to +/- 50% for the Conceptual Phase;

2. Planning (Front End Planning / Detailed Engineering or Pre-feasibility / Feasibility): In this phase, the project objectives and requirement are refined and planning starts, which are the collection of several plans that constitute a course of actions required to achieve the objective and meet the requirements of the project. The project scope is finalised during the planning phase. The project management plan, which is the outcome of this phase, contains subsidiary plans, such as the project scope, a schedule, a procurement plan and a quality plan.

   In terms of construction, the engineering team will work at creating an Area Work Plan (AWP), which will be subdivided into Engineering Work Package (EWP), and subsequently into Construction Work Package (CWP) and Field Installation Work Package (FIWP). The Procurement team will focus its works on establishing a procurement execution plan (PEP) and a logistics execution plan (LEP).

   Finally, the construction team will develop the constructability execution plan and correlate all EWP and CWP tasks. The cost order of magnitude for the expected accuracy range is limited to +/- 10% to 25% during the Planning phase;

3. Executing (Construction): In this phase, the project management team implement and execute the project plan. In accordance with the project schedule, the main output is the project deliverables. Approved changes, recommendations and defect repairs are also implemented in this stage through control and monitoring. In construction, the rules of engagement during the construction project will be executed in accordance with the contract format which is either a Time &

Materials (Cost + %) or a Lump Sum (Design Built). The cost order of magnitude for the expected accuracy range is limited to +/- 5% during the Executing phase.

4. Monitoring and Controlling (Construction): The PMBOK's monitoring and controlling phases are included in the Construction Phase. Monitoring and controlling the project includes defending the project progress and performance to identify variance from the plan, change orders and recommending preventive and corrective actions to bring the project in line with the planned expectations. The cost order of magnitude for the expected accuracy range is also limited to +/- 5% for the Monitoring and Controlling phases.

5. Closing (Commissioning & Turnover): In the Closing phase, which is part of the Construction Phase, the project owners receive the formal acceptance of the product, close any contracts involved and bring the project to an end by disbanding the project team. Closing the project includes conducting a project review for lessons learned. In the case of a construction project, it will also include commissioning activities and turning over the project to other groups such as maintenance and operational departments.

In summary, the Participant Observation methodology allows the observer (researcher) over an extended period to discover discrepancies between what various construction stakeholders say, often believe what should happen (the formal system) and what happen. The extended period of study also allows the researcher to better understand the complexity of mega-projects, which are more unpredictable and multidimensional, rather than rational and deterministic.

3.8.8. Residency no. 2: Action Research

The researcher took a new contract, between December 2014 and January 2017, as Material Manager in a mega-project that was already on-going for a year and half. The researcher's roles included transportation, field procurement, material management, and site services. Immediately after its arrival at site, the researcher was involved actively in observing, participating and proposing new courses of action, in order to help the EPC in improving its supply chain work practices, and subsequently regaining the control of their inventories at the two (2) laydowns and one (1) warehouse under their management. From a visual perception, it was evident that an apparent disorganisation of the Prime Contractor no. 1's materials and planning teams exited.

Thus, the inventory audit was ordered based on the supply chain premises, that low inventory control leads to poor business success and lost revenues, which translate in lost time, late materials and equipment deliveries and poor used of labour, and subsequently poor performance and low productivity.

So why the researcher did select an Action Research for its second residency (2015-2016) of observations? Action research is a grounded method, rooted in the realities of the situation, with a deep meaning orientation (Taggart *et al.,* 2014; Vinten, 1994). Action Research seeks to contribute to the practical concerns of people in problematic situations while contributing to the scientific knowledge in a collaborative effort (Taggart *et al.*, 2014). Moreover, an Action Research is an interactive inquiry process that balances problem solving actions implemented in a collaborative context with data-driven collaborative analysis or research to understand underlying causes enabling future predictions about personal and organizational change (Reason *et al*., 2001).

According to the researcher, an Action Research offers fresh opportunities to explore the level of supply chain robustness during construction projects. The Action Research is also a reflective process of progressive problem solving led by the planning and material teams. For this Action Research, the researcher employs the same strategic purpose as Denscombe (2010) which is based on:

- Solving a problem (lack of inventory control);
- To produce guidelines for effective practices (supply chain best practices);
- To produce guidelines for an organisation (Prime Contractor no. 1).

Action Research typically involves a cycle or spiral of five project stages (Susman *et al*., 1978). In accordance with Taggart *et al.* (2014), these Action Research's stages which are described in Figure 3.8, entail the following:

1. Diagnosing: Involving identification and defining the scope of the problem. This stage focuses on obtaining factual evidence such as the lack of level of inventory accuracy that was recorded January and December 2015.

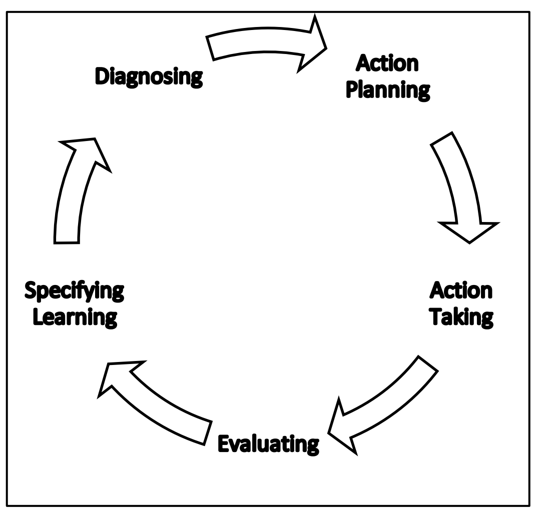
2. Action planning: Requires consideration of alternative actions for addressing the problem. For this research, data gathering began where Prime Contractor no. 1 and the Owner's CMT conducted an inventory audit simultaneously. Inventory audits were planned at two (2) laydown areas, several containers holding materials and one (1) warehouses at site that were reserved for the project.

3. Action taken: It involves implementing an improvement plan. The material quantities between the Prime Contractor no. 1's records and the audit conducted by the CMT were consolidated and accuracy values between reported quantities were calculated. Note that an attempt to quantify the monetary value for the inventories were undertaken initially, however, due to lack of cooperation from the Prime Contractor, identifying this variable was abandoned. The results are detailed in Chapter Four.

4. Evaluating: requires the study of the consequences of the actions implemented. The poor performance in material management, and other technical reasons, lead to the replacement of the Prime Contractor.

5. Specifying Learning: It is used to identify findings and suggest improvement for further iterations of the cycle.

Figure 3. 8
Action Research Cycle



Susman *et al*. (1978)

In addition to the cycle proposed by Susman *et al.* (1978) described above, another other such as Woods (2012) also prescribed a series of conditions to follow when utilizing an Action Research approach. For instance, there are six (6) conditions the research's participants in the Action Research must follow:

1. The employees of the Prime Contractor no.1 should reflect, improve, and develop their own works and their own situations by tightly integrating their reflection and action.

    - The researcher noted at several occasions a friction amongst the Prime Contractor's staffs in any internal will to improve their material processes;

2. The employees of the Prime Contractor no.1 should make their experience public not only to other participants but also to other persons interested in and concerned about the work and the problem.

    - At no time during the construction phase, where the Prime Contractor no. 1 acknowledged its weaknesses in keeping inventories under control;

3. There is increased data gathering by the research's participants in relation to the managerial problems.

    - The inventory accuracy for the Prime Contractor' mechanical and electrical departments are illustrated in the Action Research's results;

4. There is increased participation in decision making and power sharing. Self-reflection, self-evaluation and self-management by the research's participants are happening.

    - Upon the implementation of the Action Research, the researcher observed an increase participation from the Prime Contractor's field staff, however, their senior management maintained its refusal in acknowledging the importance and benefit of a strong inventory management at site;

5. The research's participants observed progressive learning by doing and making mistakes (e.g. non-recorded inventories);

6. When the self-reflection results do support the idea of the researcher, then the study is an Action Research.

    - However, as mentioned above, the cooperation between the Prime Contractor's field staff and their senior management weren't synchronize on the issue of inventory management.

Once again, the objective of this research's Action Research was based on the understanding that a well-functioning inventory management system is synonymous to a well-functioning organisation. Simply stated, if you don't have control of your inventories, it will cause lots of problems and start to disturb the execution of work orders and field installation works. A well-functioning inventory management system is a process of overseeing the flow of items into and out of field inventories. It's also a balance of having just enough products in warehouses or laydowns at site, without causing delays during field installation. Effective inventory management keeps the construction costs under control so you can run a successful project. The section below are the steps that were taken during the Action Research at the construction site, which included only the Prime Contractor No.1's facilities (1 warehouse, Top Laydown, Lower Laydown, Electrical Laydown, Iron Worker Laydown).

Action Research Step 1 – Logistics Organisational Structure

- Although the Prime Contractor no. 1 had a Material Team at site, the responsibilities for keeping inventory rested on the Civil, Mechanical, and Electrical Lead Planners;

- The planners, in fact, controlled estimating, planning, and procurement for the project;

- The Material Team controlled the transport and the reception of the materials and equipment from the supplier to the site;

- Once receive at site, the Material Team would transfer materials / equipment to the respective superintendent of each trade.

Action Research Step 2 – Implement an Inventory Management Software

- Prime Contractor no. 1 didn't have an inventory management software, except for Excel spreadsheets, not they had any back up. Near the end of their works, the contractor introduced SAP;

Action Research Step 3 – Procurement

- Having a cost + % contract terms, the Civil, Mechanical and Electrical Leads procured materials and equipment without much restrictions, and the approval process for procurement between the Owner's CMT and the Prime Contractor no. 1 was not in place.

Action Research Step 4 – Tracking Inventory

- Tracking of inventories were executed by the Civil, Mechanical and Electrical Lead Planners and the information were transferred to the Material Team;

- Once the materials and equipment were received at job site, the data were recorded (count, date, description, etc.) and stored into one of the laydowns or warehouses;

- Pictures of the materials or equipment were never recorded by the Prime Contractor's Material Team;

- The location was recorded in a general fashion (e.g.: Laydown name), however, rows or shelves were never associated with the materials or equipment;

- The transfer of materials and equipment belonged to trades' superintendents and were never signed and acknowledge between the Material Team and the superintendents themselves;

- Once materials and equipment were transferred to the superintendents, the activities of tracking ceased immediately. The period of materials / equipment releases to the time they got field installed was never recorded as a performance;

- Finally, losing materials or equipment was common and no one was accountable for it;

- Hence, they were no formal inventory management system at site, excluding the reception and the transferring processes;

- Unfortunately, the logistics organisational structure of Prime Contractor no. 1, with its lead planners in charge of procurement and the lack of inventory control at site did not provide a clear overview of their inventory accuracy;

- Accurate tracking of inventories at job site is a must;

- Having a tracking system will provide a control over the inventories and also provide you with KPIs, which some correlates with, for instances, activities in procurement, construction management, cost control, planning and scheduling;

- Whether you are using a spreadsheet or a program to keep track of inventories, a central database is necessary to ensure that all the changes are visible to everybody and that no data will be lost.

Action Research Step 5 – Stock Optimization

- Stock optimization in construction is hard to do as construction schedules often changes and keeping minimum stock level is risky;
- Keep track of the inventory at site and the relative cost values.

The methodology of an Action Research during a construction project made strong sense. However, Action Research has its limitations. According to Palsson (2007), there exist four (4) limitations between action and research objectives, such as:

1. There is a limitation either by the researcher's agenda or by the participants. In the case of this Action Research, (1) the researcher (Material Manager) attempted to conduct the audit with the outmost transparency, whereas (2) the Prime Contractor's senior management opposed to the inventory audit, due to contractual agreement and the evident cost of bearing the inventories, of which they were estimated through a non-confirmed audit between $8M and $12M;
2. Those who are motivated primarily by instrumental goal attainment or by the aim of personal, organizational or societal transformation. In the case of this Action Research, the three (3) objectives were to demonstrate: a) the Prime Contractor no. 1 did not control its inventory at site, b) the cost of non-recorded inventory had to be estimated immediately, and c) a substitution program for materials and equipment had to be introduced for the remaining areas to be built;
3. Study like Palsson (2007) states gaining access to the construction site is a very important limitation. For this research, however, the access to the construction site was never difficult to obtain, as the researcher was also actively part of the Construction Management Team;
4. Another limitation that is reflected in some studies (Palsson, 2007; Vinten, 1994) is the inevitable trade-off between the observer's privilege inside status, and the reduced level of statistical reliability that is achieved. However, the researcher would rather seek to move physically, freely and intellectually within the boundary of a construction field rather than relying on artificial modeling or abstract hypothesis.

3.8.9. Construction Contracts

Before entering into a contract agreement, a prime contractor will be selected for executing a project through a competitive bid process, which the award is made usually to the most responsive low bidder or through negotiations. The choice of contract type between the project's owner and the prime contractor is closely related to the magnitude of risk associated with the specific project. As the project moves in terms of duration, the prime contractor's risks increase in amount of materials needed and labor required to terminate a job on schedule and on budget.

To assess the overall risk, a prime contractor must analyze the complexity of the scope of work, the accuracy of design specifications, the amount of engineering / construction drawings that are completed, ready for field installation, the availability of historical pricing data, the accuracy of its own estimations versus the productivity factors, pertinent to the location, the weather, the complexity of the project, etc. The overall risks are reduced as the accuracy of work methods become more predictable.

The amount of information, which a prime contractor must provide to a project owner varies in the form of the contract. For instance, a Time & Material contract requires the prime contractor to provide performance, productivity and cost control information to the owner, who wishes to keep the project under budget and on time. Another type of construction contract is based when a prime contractor agrees into a Lump Sum contract. In this case, the contractor is only, in practice, required to provide schedule and quality performance, since the price of the project is fixed throughout the period of construction.

Time and labour are the two most critical variables in manufacturing production. Similarly, time and labour are also the two important factors in construction and have significant legal consequences. In order to protect itself against excessive delays or too many labours being hired, entering into a contractual agreement is a must for all parties. A contractual agreement is to set a rigid beginning and ending dates for the construction process. Therefore, contract pricing in construction will depend on LEM (Labour, Equipment, Materials), of which the prime contractor determines how much it will take to complete the project on time and on budget.

A construction project is characterized by a labour-intensive and a decentralization of many trade organisations. A prime contractor will self-perform a portion of the scope of work, but will also use subcontractors to support specialised works. During the mill upgrade project which the researcher took part, it is important to note the Prime Contractor no.1 began construction even though the drawings were less than 60% completed. Considering the risk analysis of the project and the percentage of drawings missing, the project owner agreed in a Time & Material (T&M) Contract with the Prime Contractor no. 1. Manifestly, a Time & Material Contract or also known as a Cost-Plus Contract is used where the scope of work is uncertain (less the 60% of drawing completed) and the costs of the project activities can easily become out of control. Whether you are a prime contractor or a subcontractor, the most popular construction contracts which protects the owners against excessive time and labour usage, are four (4) kinds of prevalent pricing methods widely used:

- Lump Sum // Fixed Price;
- Design Build // Turnkey;
- Time and Material + % // Cost Plus;
- Construction Management Team.

3.8.9.1. Time & Material Contracts

Time & Material Contract between a contractor and an owner will specify which costs are reimbursable. Typically, reimbursable costs in a T&M Contract include labour, materials, equipment, overhead, insurance, and bond premiums. Contract modifications through site instructions and change orders can also easily consume the budget. Normally, contract modifications will increase cost and will require either a diminution in quality in certain tasks, total elimination of certain aspects of the project, or the need for an additive change order to increase project funding.

Hence, T&M Contract can become expensive compared to lump sum contracts; and in this instance, the project owner is at a cost disadvantage with Time & Materials contract, whereas any prime contractor, subcontractors and union trade member will gain from extending project in duration delays. During the project itself, the Prime Contractor no.1, under a T&M contract was removed on December 2015. The second prime contractor was contracted under a Lump Sum Contract in January 2016 and completed the project in January 2017.

3.8.9.2. Lump Sum Contracts

A lump sum (LS) contract is one of the most common form of construction contract. Under a lump sum contract, a single fixed price for all the works is agreed between the project owner and the prime contractor, where the latter is responsible for executing the complete contract work. A lump sum contact is generally appropriate where the project's drawings are near completion and well defined and change orders are unlikely. The scope of work's information is reliable and means that the prime contractor is able to accurately price the project's works. Lump sum contracts might be less appropriate where speed is important, or where the nature of the scope of work not well defined.

Lump sum contracts allocate more risk to the prime contractor than Time & Material / Cost Plus contracts. There are fewer mechanisms to allow them to vary their price offers, and it give the project owners some certainty about the project final costs. Due to the level of high risk which the prime contractor become responsible, the tender process for lump sum contract will tend to be slower than any other forms of contract. Hence, preparing a tender for the project, including estimating, planning, scheduling will be more expensive for the prime contractor.

However, LS contract is not a fixed price or a maximum price. Some of the risks can also be barred by the project owner or other construction stakeholders. It is important to recognise that a truly fixed price contract would not necessarily be in the interests of a project owner as it would require that the prime contractor's price risks over which they may have no control, and which might not arise. It would also give very little scope for the project owner to alter its requirements. Consequently, the price of the lump sum contract can change due to several factors, such as:

- Change orders due to variations: These are change in the nature of the works with variations with to the design, quantities, and quality, sequence or working conditions;

- Delays in supplying materials and equipment: A relevant event may be caused by the project owner for instance, in failure to supply materials and equipment on time. Barring any circumstances caused by the project owner and outside of the control of the contractor, the contractor must meet the time set by the project owner or be penalised;

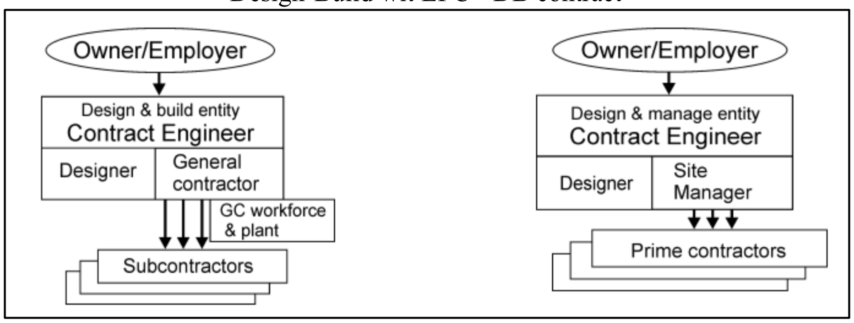
- Delays in weather: A relevant event may be caused by a neutral event such as exceptionally adverse weather and may result in a claim for loss and expense by the prime contractor. Time factors are even more complicated in construction because the working environment may be outside the control of all construction stakeholders;

- Fluctuations / Currency: A mechanism for dealing with inflation or currency changes (e.g. USD to CAD) on project that may last for several years where the prime contractor's tender was based on today's current prices. In this instance, the contract makes provisions for the prime contractor to be reimbursed for price changes over the duration of the project.

3.8.9.3. Design Build Contracts

Design Build (DB) contract is also known as a turnkey system. In DB contract, the project owner employs a single contractor providing managing, design and construction services acting as a prime contractor. There is only one contractual relationship involving the project owner and the prime contractor. The prime contractor takes over the whole responsibility for the completion of the project. The design and construction processes are under the prime contractor's responsibility, which improve information flows and shorten the time of the project delivery. Traditional conflicts between designers (engineering firms) and prime contractors (construction) are eliminated since the latter is responsible for both drawing and building the project. The organisational arrangement for a Design Build contract is illustrated in Figure 3.9.

Figure 3. 9
Design-Build wit EPC - DB contract

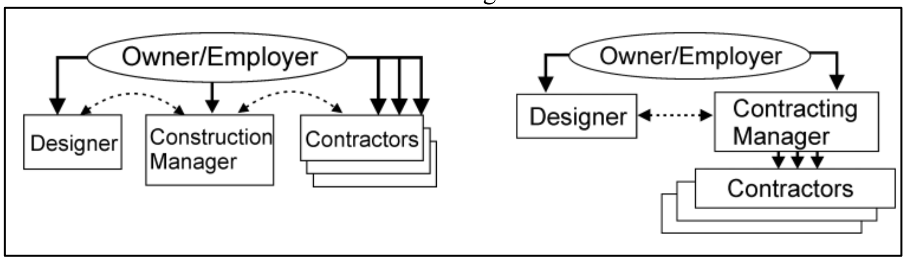


Benton *et al.* (2010)

3.8.9.4. Construction Management Team Contracts

Professional construction management systems introduce another party to the traditional triangle between owner, engineering firm and contractor: a Construction Management Team (CMT). These professionals represent the owner's interests, integrate and manage all the processes with the engineering firm and the prime contractor. CMT usually come late into the project, such near the end of the detailed engineering phase. Unfortunately, owner should utilise CMT for their expertise to support any decisions right from the conceptual phase to the commissioning end. The CMT are usually as consultants or temporary employees and always represent the project's owner. Figure 3.10 displays two (2) types of set-up for a Construction Management Team during a project.

Figure 3. 10
Construction Management Team



Benton *et al.* (2010)

3.8.10. Constructs

The research constructs are an essential part of the prescriptive knowledge of the Design-Science Research. As described in Chapter One, the researcher spent an extended period in several management positions. Through the period of research, seven (7) construction constructs were noted by the researcher to be of a repetitive occurrence:

- Construct no. 1: Diverging Objectives. This research identifies six (6) stakeholders during the construction of mega-projects. They are the project's owners, the engineering firms, the construction contractors, union halls and their tradesmen, suppliers and consultants. These stakeholders work under either the paradigm of capitalism, protectionism or generalist and all have different objectives;

- Construct no. 2: Fragmented Supply Chain Processes. The philosophy toward achieving an end-to-end supply chain approach is applied throughout several industries. Surviving today's dynamic global market requires a strong internal and external supply chain integration. The researcher observed the supply chain processes was fragmented at the construction site, even non-existent. Construction sites, in particular, don't support an end-to-end supply chain flow approach. In fact, construction sites are most likely engineering-driven or construction-driven;

- Construct no. 3: Status Quo remains in the Construction Industry. Poor productivity and lack of understanding as to why it happened, as brought the necessity for a change in how construction projects are being managed (Ballard, 2010; Cheng *et al*., 2010; Dainty *et al*., 2001; Egan, 1998; Fernie *et al*., 2007; Latham, 1994). Owners, engineering & construction management teams, union halls and contractors have different self-interests, roles and responsibilities during mega projects. Thus, trying to roll out any type of standardized solutions to a specific project is not an easy task in the construction culture of today. Hence, status quo in integrating supply chain remains the reality;

- Construct no. 4: Homogeneity in Mega-Project Management. No matter what sectors of the industries (oil & gas, mining, building & bridges) that is being built, project management is performed in a similar format. The researcher notes a construct where planning, design and construction phases are systematically approached the same way (homogeneous process) by most engineering firms, contractors and construction management companies;

- Construct no. 5: Macro-Reporting During Mega-Projects. Generally, contractors will rather tend to report their progresses in a macro-way, whereas manpower hours will be grouped under one general area of works instead of breaking it down to several categories. Usually, the more progression and performance details that are demanded by construction management team (CMT) and owners, the higher the resistance from contractors and union halls in reporting them;

- Construct no. 6: Changes Are Costly. As observed during this project, changes were regarded as inevitable and most likely presented to the owner with additional costs (labours and materials). Rarely the owner encounters cost reduction over change. Hence, changes are generally seen as a major contributor to the managerial problems of being over budget and late deliveries in the construction industry (Lazarus *et al*., 2001);

- Construct no. 7: Uncertainty is Common. Going into a mega-project with known certitude of events is simply impossible. Uncertainty is a key factor influencing performance and an important unknown measurement for the operating environment. According to Gallear *et al*. (2013), uncertainties have a major impact on managerial decisions. Uncertainty also diminished the ability to align the construction stakeholders with the demands of the internal and external environment. Uncertainty also brings intentional chaos, where contractors nickname this situation as *Chaos is Cash*. In other words, uncertainty promotes lack of decision, delays, mistakes, reworks, and so on, creating more work hours for the labour, more revenues for the contractors and subsequently increase project costs and late deliveries.

3.8.11. Enriched SCOR Model

According to Chan *et al*. (2014), there exists no structural framework using a supply chain management approach in a construction environment. This research proposes the use of a supply chain framework, adapted to construction characteristics. The necessity for a change in how construction projects are being managed, have been stressed by many authors (Ballard, 2010; Karim *et al.,* 2006, Latham, 1994; Egan, 1998). In according to Changali *et al. (2015)* of the consulting firm McKinsey & Co., introducing supply chain processes may be an opportunity to improve projects' success in term of budget and time.

Thus, the growing attention to supply chain performance in construction should be measured and analyzed (Gunasekaran *et al*., 2004). Therefore, to know whether supply chain processes are being effectively implemented in a construction project, one has to measure the end-to-end flow process. In construction, it begins at the conceptual phase, then moving on to the front-end planning and detailed engineering and more importantly, during the construction phase. Akyuz *et al.* (2010), (1999) Erkan (2010) and Beamon (1999) conducted comprehensive reviews of supply chain models and concluded that the current ones suffered from the following limitations:

- Models in literatures focus on cost as the primary measurement of performance;
- Models relying on cost measurement are insufficient and could be potentially misleading;
- Models tend to rely on single, mainly economic-oriented, supply chain performance measurement;
- Models ignore the interactions among different stakeholders' strategies;
- Models don't consider all phases of project management;
- Models ignore the potential influence of uncertainty, which is outside management control, but has a strong influence on supply chain performance;
- Models ought to reflect a multiplicity of goals and outcomes, and they should include quantitative and qualitative measures;
- Measurements used should take into account the effect of contexts or situation-related factors;
- Measurements should be compared and contrasted against the best possible potential performance (KPI) related to construction.

The Supply Chain Operations Reference (SCOR) Model is one of the best tools to measure the effectiveness of supply chain amongst manufacturing industries. The model's framework covers all aspects of manufacturing, from suppliers, to operation and end-customers. However, many authors such as Cheng *et al*. (2010); Gunasekaran *et al*. (2004) and Johansson *et al*. (2011) and have argued the SCOR model, by itself, must be adapted to better embrace the activities of construction project management. The researcher decided to keep the SCOR Model, as a base framework, enriched it with specific construction attributes and metrics and subsequently tested it with semi-structured interviews and one survey.

3.8.12. Semi-Structured Interviews

The researcher employed semi-structured interviews in a way of gathering data from the enriched SCOR Model, with the process of reducing the number of performance attributes and metrics in order to meet the research objectives, such as offering construction stakeholders a new and improved model, friendly and easy to use, covering all phases of mega-projects.

The human use of language is fascinating both as a behaviour in its own right and for the virtually unique window that is opened on what lies behind the interviewees' actions (Robson, 2002). Interviews are widely used in social science and commonly defined as either structured, semi-structured and unstructured interview.

The semi-structured interviews provided the flexibility and adaptable way of findings explanations on what construction stakeholders thought of their environment. Similar to Robson (2002), the semi-structured interviews for this thesis had predetermined questions, but the order of the questions were allowed to be modified, based on the interviewer's (researcher) perceptions of what seem most appropriate for the time in place.

The semi-structured interviews were considered by the researcher as exploratory works and focused on the qualitative and quantitative studies of this thesis. The kind of interviews for this research included in person, Skype, and telephone.

1. Face-to-face interviews offer the greatest flexibility possibility to investigate a topic. They enabled the researcher to modify the way the sequence of the interviews was conducted, following up interesting answers in more details, and investigating the underlying motives in way, that Skype or telephone interviews cannot perceive.

   There was also an opportunity given to the participants to discuss important key topics, if desired. Interviews are used to enrich the discussions and further validate the research results. The participants' remarks, comments, feedback and what were important to them, regarding the global failures in project management were recorded in Chapter Four - Results.

2. Telephone interviews provided a means of capitalizing on many of the advantages of survey and substantially reduced the time and resources involved in running face-to-face interviews by cutting out travelling time. Due to the various regions and countries the participants reside, the researcher leaned toward telephone interviews. It is important to note the researcher received no funding during the entire period of research.

3. Skype interviews were also completed with participants living overseas. The benefits of Skype interviews were: a) save traveling time for the researcher; b) it allowed both researcher and participants to be wherever they need to be; c) the researcher can gain the visual impression of the participants;

The researcher tested the interview document prior its general sending with its thesis director and two senior managers which were active in the construction phase. In total, three (3) revisions for the semi-structured interviews took place. They are described in Chapter Four as: a) rev original, b) rev 1, and c) rev 2.1. From the results obtained during the interviews, the researcher was able to build a survey, using the Monkey Survey platform.

3.8.13. Survey

At first, the researcher opted for the SCOR Model's framework, and enriched the original model by adding some performance attributes and metrics related to engineering, procurement and construction management's activities during mega-projects. This enriched SCOR Model became too large and had to be reduced in order to meet the research objectives. This reduction of attributes and metrics was achieved through a series of semi-structured interviews. The reduction gave the researcher a general view of performance attributes and metrics needed during mega-projects. However, this reduction did not account the participants' views during a specific type of contract. In other words, certain metrics during a Lump Sum contract may not score the same robustness in a Time & Material contract, hence the utilities of metrics are appreciated differently, depending on what types of contracts a mega-project is executed.

In order to measure the effects of various contracts over construction stakeholders, the researcher decided to test the participants that took part in the semi-structured interviews with one survey. The final objective of this survey was to reduce and optimise in the same time, the amount of performance attributes and metrics, when faced with a certain type of contract.

Among the different methods of gathering data in research, the survey method is preferred by many researchers due to various advantages. Surveys are used to increase knowledge in fields such as social research and are often used to assess thoughts, opinions, and feelings with large number of participants. Surveys can represent a specific and limited field of speciality, such as the mega-projects used in this thesis. Surveys can also have more global, widespread goals. In contrast to the semi-structured interviews, surveys will answer to a set of questions, might be quite consistent, but is less likely to show conflicts between different aspects of the social system or between conscious representations and behavior (DeWalt *et al.,* 1998).

Survey Benefits

Web-based surveys have several advantages over paper-based surveys such as cost, increase accuracy and faster analysis of data. For instance, the advantages of conducting surveys are:

1. Representation of the participants: This survey was able to extract data representing senior managers involved in engineering and construction management.;

2. Low costs of conducting surveys: The researcher opted for the free version of Survey Monkey. Time to compose the letter of introduction, information & consent letter, and build this survey on Survey Monkey was free of charge. Since there was a cost to download the results from Survey Monkey, the researcher chose to use Windows' snipping tool and gathered all data under Words and Excel sheets;

3. Convenience of data gathering: The researcher was able to collect data from participants from several provinces in Canada, and countries like the United States, Niger, France and Spain;

4. Statistical significance: Surveys offer great statistical results when there is a large amount of representativeness. In the case of this thesis' survey, the researcher recognizes the limitation of statistical significance for the results obtained due to number of participants (less than fifty). However, the limitation in number of participants is counteracted by the high quality of the same participants in terms of diversities in job positions and years of experience for each participant in mega-projects. In conducting the survey, the researcher selected a heterogeneous sample of engineering and construction professionals that have worked in mega-projects for several years. The profiles of participants are demonstrated in Chapter Four;

5. No subjectivity: In a sense, surveys are ideal for scientific studies because they provide standardization and the participants' answers are less submitted to the researcher's subjectivity;

6. Precise results: The questions in the survey cover all activities of construction project management and provide uniform definitions to all participants. Subsequently, there is a greater precision in terms of measuring the data gathered;

7. This survey, in the eye of the researcher, is non-intimidating, as all participants answered the survey in positive ways;

8. Understanding that participants are more likely to provide open and honest feedback in a more private survey method, selecting the Survey Monkey web format was a strong approach toward receiving non-biased answers.

Survey's Limitations

1. Inflexible Design: Once the surveys are sent by emails, they can't be changed throughout the process of data gathering, as opposed to interviews, which can adapt to new ways of asking a question. Although this inflexibility can be viewed as a weakness for this survey method, this can also be a strength because preciseness and fairness remain constant throughout the survey;

2. Surveys are not ideal for addressing controversial issues: However, this limitation can be ignored for this thesis, as there were no controversies during the thesis;

3. Possible inappropriateness of questions: This limitation can also be can ignored as the related questions regarding performance attributes and metrics were tested during the interviews, and prior formulating in the final survey;

4. The primary limitation for this thesis is the fact all interviews and survey were not conducted in any other mega-projects. The researcher acknowledges the valuable feedback if the artifact had been tested in other projects.

The questions in the survey cover a wide range of project activities, including performance attributes and level metrics representing every aspect of construction project management. Each question was strategically planned and structured in order to receive the most accurate data, for a construction environment. When structuring the survey questions, the researcher considered the following elements of importance:

- The survey questionnaire for this research has been built upon the results from the semi-structured interviews;

- A web-based survey named Survey Monkey, was then composed for this survey. The preferred used of this web-based survey software is well supported over practical problems with the paper-based form of data collection (Illieva *et al*., 2002, Thompson *et al*., 2003);

- Prior to sending the email and the web-page survey to participants, the main goal of the survey was explained by phone;

- In conducting a survey, the researcher was be able to elicit opinions, attitudes and beliefs of a sample group regarding some issues of interest. Survey responses were then transferred onto a worksheet. These answers can be found in Chapter Four.

Finally. the survey's responses were tested to find out which optimal performance attributes and metrics were the most robust amongst the four (4) different types of construction contracts: a) Time & Materials contacts with respect to Owners, b) Time & Materials contracts with respect to Contractors, c) Lump Sum contracts with respect to Owners, and d) Lump Sum contracts with respect to Contractors.

The results of the survey data will be made available to participants, if they desire so, and the researcher is committed to a broad diffusion as expected by the methodology of Design-Science Research. The researcher demonstrates in Table 3.3, the survey's metrics.

Table 3. 3
Survey's Matrix

	T&M	LS
Owners	Performance Attributes Level I Metrics Level II Metrics Level III Metrics	Performance Attributes Level I Metrics Level II Metrics Level III Metrics
Contractors	Performance Attributes Level I Metrics Level II Metrics Level III Metrics	Performance Attributes Level I Metrics Level II Metrics Level III Metrics

Dany Julien (2019)

3.8.14. Artifact: CPPM

Once the survey analysed, the final objective of this Design-Science Research is centred at the development of its artifact (design). Hence, the artifact in a Design Science Research is the final output and makes up the soul of this thesis. The construction literature is more united on measurements such as tracking time and position, and less inclined on trying to understand the supply chain processes (Gallear *et al*., 2014; Melnyk *et al*. (2004).

To remedy this divided approach, this research selected the framework belonging to the SCOR Model, and applied modifications gained through a Participant Observation, an Action Research, seven (7) constructs, semi-structured interviews and one survey. The end-result is the conception of the thesis' artifact, titled Construction Performance & Productivity Model (CPPM).

Gregor *et al.* (2013) proposed that an artifact contributes to the industry (e.g. construction) by improving the prescriptive knowledge at three (3) different levels. These prescriptive knowledges are presented in Table 3.4.

Table 3. 4
Design-Science Research Contributions

Design Science Research Contribution Types		
	Contribution Types	**Example Artifacts**
More abstract, complete, and mature knowledge	Level 3. Well-developed design theory about embedded phenomena	Design theories (mid-range and grand theories)
↕ ↕ ↕ ↕	Level 2. Nascent design theory—knowledge as operational principles/architecture	Constructs, methods, models, design principles, technological rules.
More specific, limited, and less mature knowledge	Level 1. Situated implementation of artifact	Instantiations (software products or implemented processes)

Gregor *et al*. (2013)

1. Level One Contribution – Instantiations: Artifacts are often constructed to evaluate the level of improvement in comparison to with instantiations of existing solution artifacts. For this research, after reviewing literatures in supply chain management and construction management, the researcher concludes that SCOR Model was the best model offered for the industry, however, based on personal experience in mega-projects and supported by literature, the researcher did not believe in the model being efficient and effective for the construction industry. Hence, a new artifact (design) was designed in order to cover all activities of construction project management. Furthermore, the researcher states the SCOR Model did not meet Level One in DSR Contribution and must be improved by a modified model (CPPM);

2. Level Two Contribution - Model: The artifact which is proposed in this thesis is a research improvement. The operational framework of the new artifact (CCPM), meets Level Two Contribution;

3. Level Three Contribution – Knowledge Contributions: In this level, the evaluation of the artifact will lead to knowledge contributions in the form of descriptive knowledge. Furthermore, the kernel theories will formulate into a new mid-range design theory as a result of new understandings of the problems and

> solutions. Hence, this thesis states the new design, which replaces the SCOR model partially meet Level Three, since the artifact was not tested in other construction sites (see Chapter Four – limitations).

The proposed CPPM is heavily influenced by supply chain processes, such as the ones on manufacturing's and the performance attributes discussed in the SCOR Model. Thus, the artifact presented in this thesis had been enriched, reduced and optimised in order to meet the constraints, challenges and complexities of construction project management. Overall, the artifact (Construction Performance & Productivity Model) provides a standard framework with descriptions and inter-independence between processes (Gulledge *et al*., 2008; Thunberg *et al*., 2014). Likewise, the standard process framework of the CPPM provides a common language to facilitate horizontal process integration across different stakeholders and departments in the value chain of project management.

In addition to using a supply chain framework, the CPPM moves away from typical project management frameworks, such as the ones expressed in PMBOK, CII and the COAA, which are for the most parts, engineering-driven approaches. Thus, the CPPM leans on adopting a supply chain framework, which includes engineering and construction management in co-existence with procurement, cost control, workers management and project complexities. In fact, the CPPM focuses its effort on tracking performance and productivity across all phases of construction project management, by measuring performance attributes and metrics related to seven (7) project activities, including:

- Procurement Reliability;
- Procurement Responsiveness;
- EPCM Agility;
- Project Control;
- Employee Management;

- Project Complexity;
- Project Integration.

3.8.14.1.Procurement Reliability

The first performance attribute, illustrated by the researcher in Figure 3.11, is the measurement of procurement reliability. The objective of this first attribute is for a procurement department to deliver the correct product at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct place (warehouse / laydown) for the end customers. Reliability focuses on the predictability of the outcome to process and the ability to perform tasks as expected. Typical metrics for measuring procurement reliability are unitized such as time, quantity, quality.

Figure 3. 11
Procurement Reliability – CPPM

Construction Performance & Productivity Model							
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Detailed Engineering** **2. Constructability** **Construction:** **3. Execution**	**Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Return**	**Quantitative**	**I. Procurement Reliability**	1. Delivery Performance	1.1. Scheduled Purchase Orders Made by Owner's Request 1.2. Delivery Performance Against Owner's Requested Date 1.3. Delivery Performance by Suppliers' Committed Date 1.4. Perfect Orders' Fulfillment 1.5 Purchase Orders' Quality & Accuracy 1.6 Invoices' Accuracy	1.1: 10 metrics 1.2: 6 metrics 1.3: 5 metrics 1.4: 2 metrics 1.5: 7 metrics 1.6: 10 metrics Total: 40 metrics

Dany Julien (2019)

Procurement reliability is conducted during the pre-construction and construction phases. Procurement activities usually start during the detailed engineering phases where management will target the long lead items (6+ months). Procurement activities will be carried onto the construction sites where the material managers will usually take over the responsibilities to order materials and equipment under field procurement. This performance attribute reflects the four (4) processes belonging to the SCOR model (Plan, Source, Make, and Return).

3.8.14.2.Procurement Responsiveness

The second performance attribute of the CPPM is set by measuring procurement responsiveness. It is for a procurement department to quantify the speed at which the department provides products to its engineering / materials / construction teams. The responsiveness is measured with the average actual cycle time (days) to fulfill customer order. The various metrics for this performance attribute is illustrated by the researcher in Figure 3.12.

Figure 3. 12
Procurement Responsiveness

Construction Performance & Productivity Model							
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Detailed Engineering** **2. Constructability** **Construction:** **3. Execution**	**Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Return**	**Quantitative**	**II. Procurement Responsiveness**	2. Purchase Order Fulfillment Cycle Time	2.1 Purchase Order Entry Completed 2.2 Invoice Received at Owner 2.3 Inquiry Time - Procurement	2.1: 5 metrics 2.2: 4 metrics 2.3: 2 metrics Total: 11 metrics

Dany Julien (2019)

Procurement responsiveness is conducted in parallel with procurement reliability, during the pre-construction and construction phases. Procurement activities usually start during the detailed engineering phases where management will home on the long lead items (6+ months). Procurement activities will be carried on to the construction fields where the material managers will usually take over the responsibilities to order materials and equipment. This performance attribute reflects the four (4) processes belonging to the SCOR model (Plan, Source, Make, Return).

3.8.14.3.EPCM Agility

EPCM agility is the third performance attribute that measure the ability, flexibility and adaptability for three (3) groups (Engineering, Field Procurement, and Construction Management). EPCM Agility responds to external and internal influences, their abilities to respond to changes, to maintain or improve the project's scope objectives. This third performance attribute measures a variety of data, such as delivery on time and on budget, field reworks and changes, field instructions, safety measures, delays, and so on. EPCM agility displays the largest number of Level II and III metrics within the proposed CPPM design. The researcher illustrates in Figure 3.13 the various metrics for this third attribute.

Figure 3. 13
EPCM Agility

Construction Performance & Productivity Model							
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Conceptual Design** **2. Front-End Planning** **3. Detailed Engineering** **4. Constructability** **Construction:** **5. Execution** **6. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver** **Return**	**Quantitative**	**III. EPCM Agility**	3. "E" Engineering 4. "P" Procurement 5. "CM" Construction Management	3.1 Engineering Changes 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks 3.5 Quality - NCR 4.1 Material Management 4.2 Transportation Management 4.3 Leased Equipment Availability 4.4 Inventory Management 4.5 Bagging / Expediting at Site 4.6 Reverse Logistics 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning 5.5 Document Control 5.6 Information Technology 5.7 Contract & Labour 5.8 Health, Safety & Environment	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 4 metrics 3.5: 18 metrics 4.1: 19 metrics 4.2: 6 metrics 4.3: 3 metrics 4.4: 5 metrics 4.5: 4 metrics 4.6: 3 metrics 5.1: 12 metrics 5.2: 5 metrics 5.3: 23 metrics 5.4: 9 metrics 5.5: 2 metrics 5.6: 4 metrics 5.7: 8 metrics 5.8: 17 metrics Total: 161 metrics

Dany Julien (2019)

The EPCM Agility along with project controls, are the two performance attributes which are present in all phases of construction project management and also covers all five (5) processes (Plan, Source, Made, Deliver, Return) that are noted in the SCOR model.

3.8.14.4. Project Controls

The fourth performance attribute of the CPPM is Project Controls. This attribute tries to understand the cost associated with operating a project from a conceptual phase to the front-end planning and detailed engineering, to end with the construction phase. KPIs used in Project Controls are at first known as estimate, and further one refined into cost completion. The researcher illustrates in Figure 3.14 the various metrics for the Project Control's attribute.

Figure 3. 14
Project Controls

Construction Performance & Productivity Model							
6	4	4	2	7	14	50	346
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Conceptual Design** **2. Front-End Planning** **3. Detailed Engineering** **4. Constructability** **Construction:** **5. Execution** **6. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver** **Return**	**Quantitative**	**IV. Project Controls**	6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends 7.3 Rework Spends 7.4 IT Integration Spends 8.1 Transportation Spends 8.2 Customs Spends 8.3 Warehouse / Laydown Spends 8.4 Inventory Carrying Costs 9.1 Suppliers Spends 9.2 Purchase Order Costs	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics 7.3 4 metrics 7.4 1 metrics 8.1 6 metrics 8.2 2 metrics 8.3 3 metrics 8.4 7 metrics 9.1 6 metrics 9.2 3 metrics Total = 52 metrics

Dany Julien (2019)

Similar to the EPCM agility performance attribute, the Project Control's metrics are present in all six (6) phases of construction project management and also covers all five (5) individual processes that are noted in the SCOR Model.

3.8.14.5. Workers (Employees) Management

Workers management is the fifth performance attribute and measures the effectiveness of an organisation in managing its primary asset (Labor Force + Managerial Staffs). The original performance attribute in the original SCOR model (Supply Chain Asset Management) has been removed from the proposed artifact, due to its lack of inappropriateness when dealing with construction project management. For instance, metrics like cash-to-cash cycle time and return on supply chain fixed assets or return on working capital have no construction uses during a project. Hence, the performance attributes known as supply chain asset management has been replaced by Workers (employee) Management. This new performance attribute includes tradesmen and managerial staffs. The researcher illustrates in Figure 3.15 the related metrics for this fifth attribute belonging to the CPPM.

Figure 3. 15
Workers (Employees) Management

Construction Performance & Productivity Model							
6	4	4	2	7	14	50	346
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Detailed Engineering** **2. Constructability** **Construction:** **3. Execution**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver**	**Quantitative**	**V. Workers (Asset) Management**	10. Workers' Information	10.1 Labour Force's Information 10.2 Management Information	10.1 13 metric 10.2 10 metric Total = 23 metrics

Dany Julien (2019)

The consideration of hiring tradesmen and construction staffs commence during the detailed-engineering phase. Construction management teams will commence to plan for placing construction specialists at site, account for the optimal number of tradesmen, and investigate with the prime contractor's past performance, and understand which union halls can fulfill the various roles.

3.8.14.6. Project Complexity

The Construction Performance & Productivity Model takes for account two important complexity dimensions – the off-site complexity and the complexity at a job-site. The level of complexity in a mega-project starts to unfold as early as the front-end planning phase and carries on throughout the project, to terminate at the close-out phase. It is understood that high levels of project complexity, left unmanaged, will quickly affect operational performance and lead to higher costs and most likely, late deliveries. The researcher shows in Figure 3.16 the various metrics for this sixth performance attribute of the CPPM.

Figure 3. 16
Project Complexity

Construction Performance & Productivity Model							
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Front-End Planning** **2. Detailed Engineering** **3. Constructability** **Construction:** **4. Execution** **5. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver**	**Quantitative & Qualitative**	**VI. Project Complexity**	11. Off-Site Complexity 12. Job Site Complexity	11.1 Manufacturing Complexity 11.2 Distribution Complexity 11.3 Supplier Base Complexity 11.4 IT Base Complexity 12.1 Contractor Base Complexity 12.2 Management Team / Owner Representatives	11.1 2 metrics 11.2 9 metrics 11.3 3 metrics 11.4 5 metrics 12.1 47 metrics 12.2 13 metrics Total = 79 metrics

Dany Julien (2019)

3.8.14.7. Project Integration

Measuring the level of maturity amongst manufacturers is quite simple when companies have access to data archive amongst their industrial sectors. Unfortunately, the level of maturity for a mega-project can't be measured the same way as each project is unique and short terms in time span.

Instead, the researcher believes the attribute name Level of Maturity, found in SCOR Model, must be replaced by the Level of Integration during a project. Hence, the seventh and last attribute is the CPPM framework evaluates how well a project team integrates multiple phases (from conception to closed out), from integrating multiple processes together (from plan to return), from integrating attributes (procurement, engineering, control, construction management, etc.). The researcher illustrates in Figure 3.16 the various metrics related to this seventh performance attribute. The level of project integration should commence as early as the Front-End Planning phase and be measured throughout the project until project Closed-Out phase.

Figure 3. 17
Project Integration

Construction Performance & Productivity Model							
Project Phases	**Construction Activities**	**Supply Chain Processes**	**Metho**	**Performance Attributes**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Front-End Planning** **2. Detailed Engineering** **3. Constructability** **Construction:** **4. Execution** **5. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver** **Return**	**Qualitative**	**VII. Project Integration**	Performance Analyti	14.1 Level I and Level II metrics' integration 14.2 Level II and Level III merics' Integration	366 metrics

Dany Julien (2019)

FOURTH CHAPTER
RESULTS

The researcher used a variety of complementary research methods, including Participation Observation, Action Research, semi-structured interviews and survey, along with handwritten documents and notes, constructions and hundreds technical articles. The degree of participations and observations varied in facts and in time during this episodic research.

The results obtained in this chapter were the effort of having spent two (2) years through a Participating Observation methodology, while acting as Transport & Logistics Manager, and two (2) years at a construction site, while conducting an Action Research methodology with a Prime Contractor. Thus, the results from these two (2) methodologies served as building blocks for the semi-structured interviews and survey to come in this chapter. These interviews and survey were internally validating with the observations and data recorded during this research. Furthermore, the researcher was able to appreciate the level of supply chain integration within mega-project processes, as well as beliefs, motivations, and behavior of engineers, construction and procurement specialists involved during both residencies

4.1. RESIDENCY no. 1: PROJECT FLOW ANALYSIS

4.1.1. Introduction

The researcher while working at the engineering firm and at several construction sites observed (Construct no.4) that project and construction managers tend to use similar (homogenous) planning and execution processes, no matter what project's size. Coincidently or not, project management tend to be homogeneous, and mega-projects tend to be completed over budget and delivered late. During his latter years at the firm, the researcher and with the assistance of its co-workers created the Project Flow Chart. The Project Flow Chart is illustrated in Appendix E2.

Using the Project Flow Chart as the base of its review, the researcher opted to introduce the Participation Observation methodology to measure the number of supply chain activities during all phases of mega-projects. The measurement was simply divided into two questions: a) Yes: This activity pertains to a supply chain process since it treats material flows, or b) No: This activity doesn't pertain to a typical supply chain process. The results of the number of supply chain activities per phases of construction project management are illustrated in Appendix E3 through E8.

There are many ways to describe the numerous phases of project management. Essentially, projects will go through the following cycle including, initiation, planning, executing, monitoring and controlling, and closing. The following six (6) sections describes the phases of construction project management that are illustrated in the Project Flow Analysis (Appendix E2). Furthermore, the reader should note the researcher did not retain the project framework of the PBMOK, CII or COAA.

4.1.2. Conceptual Phase

The first phase of project construction management is known as the Conceptual Phase and two (2) groups of activities were observed from the Project Flow Chart. There were (1) Business Development and (2) Proposal Process. Together, these two (2) groups of activities included a total of fifty (50) activities, which are illustrated in Appendix E3.

Overall, the Conceptual Phase had the second highest (38%) amount of supply chain activities in terms of percentage, behind the Detailed Engineering Phase with 46% and Construction Phase at 35%. The researcher illustrates in Table 4.1 the results of the Conceptual Phase.

Table 4. 1
Conceptual Phase

CONCEPTUAL PHASE	
Participation Observation at Engineering Firm	
No of Conceptual Activities	50
No of Supply Chain Activities	19
% of Supply Chain Activities	38%

Dany Julien (2019)

4.1.3. Front-End Planning Phase

The second phase of project construction management is known as the Front-End Planning Phase and three (3) groups of activities were observed from the Project Flow Chart. There were (1) Preliminary Designs & Studies, (2) Project Initiation & Planning, and (3) Project Communication, Document Control & Distribution. These three (3) groups of activities included a total of seventy-two (72) activities and are illustrated in Appendix E4.

The Front-End Planning Phase had only five (5) supply chain related activities, resulting in the second lowest percentage with a low of 7%. The researcher illustrates in Table 4.2 the results of supply chain activities during the Front-End Planning Phase.

Table 4. 2
Front-End Planning Phase

FRONT-END PLANNING PHASE	
Participation Observation at Engineering Firm	
No of Front-End Planning Activities	72
No of Supply Chain Activities	5
% of Supply Chain Activities	7%

Dany Julien (2019)

4.1.4. Front-End Planning & Detailed Engineering Phases

The next phase that was observed in the Participant Observation was a mixture of two (2) phases: Front-End Planning and Detailed Engineering. This category was created since the researcher felt the activities belong to could easily be categorised as Front-End Planning and/or Detailed Engineering.

In this hybrid phase, the Participant Observation recorded six (6) categories, which included (1) Planning & Scheduling, (2) Progress & Performance Measurement, (3), Customer Satisfaction, (4) Change Control, (5) Administration, Invoicing & Account Payable, and (6) Financial Reporting, Cost Analysis and Forecasting. These six (6) categories when combined, amounted to a total amount of seventy (70) activities. They are illustrated in Appendix E5.

Surprisingly to the researcher, the hybrid phase demonstrated no supply chain activities. The researcher illustrates in Table 4.3 the results of the hybrid phase, which includes the phases of Front-End Planning and Detailed Engineering.

Table 4. 3
Front-End Planning & Detailed Engineering Phases

FRONT-END PLANNING & DETAILED ENGINEERING PHASES	
Participation Observation at Engineering Firm	
No of Front-End Plan. + Detailed Engin. Activities	70
No of Supply Chain Activities	0
% of Supply Chain Activities	0%

Dany Julien (2019)

4.1.5. Detailed Engineering Phase

The fourth phase of project construction management is known as Detailed Engineering. This phase employs the most number of “office staffs” during the project; including engineers, estimators, cost controllers, procurement, legal staffs, and construction specialists, to name a few. The Project Flow Chart showed the Detailed Engineering Phase to include five (5) groups of activities. There are (1) Detailed Design, (2) Purchasing Process, (3) Subcontracting Process, (4) Vendor Data Review Process, and (5) Labour Relation Process. These five (5) groups of activities comprised a total of ninety-seven (97) activities and are illustrated in Appendix E6.

The Detailed Engineering Phase had the highest percentage (46%) of supply chain activities amongst all phases of mega-projects. The researcher illustrates in Table 4.4 the results for the Detailed Engineering Phase.

Table 4. 4
Detailed Engineering

DETAILED ENGINEERING PHASE	
Participation Observation at Engineering Firm	
No of Detailed Engineering Activities	97
No of Supply Chain Activities	45
% of Supply Chain Activities	46%

Dany Julien (2019)

4.1.6. Construction Phase

The fifth phase of project construction management is known as the Construction or Execution Phase. The Construction Phase employs the most staffs during the construction execution. Hundreds to thousands of people will make up the crews and staffs, which include corporate and site management, contractors and subcontractors, consultants and union halls. The Construction Phase is very complex and dynamic endeavour. The Project Flow Chart demonstrated seventeen (17) groups of activities in the Construction Phase. There were (1) Information Technology, (2) Field Submittal Control, (3) Quality Surveillance Subcontract Works, (4) Non-Conformances, (5) Requests for Information, (6) Field Engineering, (7) Inspection, Testing and Test Equipment, (8) Mechanical Completion, (9) Tool & Equipment Control, (10) Field Order Process, (11) Safety, (12) Progress & Safety Photographs, (13) Back Charges, (14) Construction Equipment, Process Equipment & Materials, (15) Mobilize, (16) Material Receipt & Warehousing, and (17) Demobilizing. In total, these seventeen (17) groups of activities amounted to a total of one hundred and thirty (130) activities and are illustrated in Appendix E7.

The Construction Phase has the third highest percentage (35%) of supply chain activities, just behind the Conceptual Phase at 38%. However, the Construction Phase had the highest number of supply chain activities with forty-six (46). The researcher illustrates in Table 4.5 the results for the Construction Phase.

Table 4. 5
Construction Phase

CONSTRUCTION PHASE	
Participation Observation at Engineering Firm	
No of Construction Activities	130
No of Supply Chain Activities	46
% of Supply Chain Activities	35%

Dany Julien (2019)

4.1.7. Closed-Out

The sixth and last phase, sometime combined with or after the Construction Phase, is the Closed-Out Phase. The Participant Observation noted only one (1) group, which is the Project Closed-Out Report. The researcher noted only four (4) activities, of which 25% of activities belonging to supply chain activities. The activities are illustrated in Appendix E8, whereas the researcher illustrates in Table 4.6 the results for the Project Closed-Out Phase.

Table 4. 6
Closed-Out Phase

CLOSED-OUT PHASE	
Participation Observation at Engineering Firm	
Project Closed-Out Report	
No of Closed-Out Activities	4
No of Supply Chain Activities	1
% of Supply Chain Activities	25%

Dany Julien (2019)

4.1.8. Conclusion – Project Flow Analysis

In conclusion, the average amount of supply chain activities in the Project Flow Chart created by the researcher and its co-workers (senior management) was observed through a Participant Observation to contain 27% of them. Detailed Engineering and Construction Phases recorded forty-five (45) and forty-six (46) supply chain activities respectively, or in terms of percentage, 46% and 35% each. These number of supply chain activities during these two (2) phases important phases illustrate their importance during projects.

On the other hand, the Front-End Planning and the hybrid phase (Front-End Planning & Detailed Engineering) illustrate the near-absence of supply chain consideration during the early phase of planning in mega-projects. The researcher points out a future research opportunity in studying the absence of supply chain activities during the planning of mega-projects. The researcher illustrates in Table 4.7 the strength of the overall supply chain activities.

Table 4. 7
Overall SC Activities in CPPM

CONSTRUCTION PROJECT MANAGEMENT PHASES			
Participation Observation at Engineering Firm	No Activities	SC Activities	%
Conceptual	50	19	38%
Front-End Planning	72	5	7%
Front-End Planning & Detailed Engineering	70	0	0%
Detailed Engineering	97	45	46%
Construction	130	46	35%
Project Closed Out	4	1	25%
Total	423	116	27%

Dany Julien (2019)

4.2. RESIDENCY no.2: INVENTORY ANALYSIS

The researcher took a new contract, between December 2014 and January 2017. Immediately after its arrival at site, the researcher was involved actively in observing, participating and proposing new courses of action, in order to help the EPC in improving its supply chain work practices, and subsequently regaining the control of their inventories at the two (2) laydowns and one (1) warehouse under their management. From a visual perception, it was evident that an apparent disorganisation of the Prime Contractor no. 1's materials and planning teams exited.

This second residency, through the methodology of an Action Research (2015-2017) was able to diagnose, plan, act and evaluate the poor management of inventories and the lack of supply chain robustness during the mega-project underway.

4.2.1. Diagnosis

The second construct in this research states that construction sites generally demonstrate some types of fragmented supply chain processes. In order to support this construct, the researcher went on to measure the level of material inventories and its accuracies belonging to the Prime Contractor's two (2) majors divisions, which were the Electrical & Instrumentation Division and the Mechanical Division.

Following the apparent (visual) disorganisation of the Prime Contractor no. 1's Material and Planning teams, the diagnosis started immediately after the arrival of the researcher at the construction site. An audit conducted over the site's inventories located at two (2) different laydowns and one (1) warehouse was undertaken over a period of twelve (12) months (January and December 2015). Hence, the improvement approach of the audit was conducted through the methodology of an Action Research.

4.2.2. Action Planning

Data gathering of inventories began when the Owner's CMT (executed by the researcher – Material Manager) conducted an audit of the equipment and materials inventory pertaining to all electrical, instrumentation and mechanical departments.

The first observation noted by the researcher was the fact that the Prime Contractor's inventory management was curiously led by the planning department for each department (E&I and Mechanical). On the other hand, the Material Team, which would normally control the inventories at any construction site, was relegated to just two (2) functionalities: to receive and place into inventory or return any over, short damaged (OSD) parts. Overall, the Material Team had no cross-departmental functionality with the construction leads or the planners. The researcher focused on changing the dominant construction culture, where supply chain consideration was irrelevant to the eyes of the Prime Contractor's management.

4.2.3. Action Taking

The material quantities reported by the Prime Contractor no. 1 were cross-referenced by the CMT (i.e. the researcher) with six (6) locations related to the electrical & instrumentation materials; and eleven (11) locations for the mechanical materials. Overall, the inventory audit recognized seventeen (17) material codes for these two (2) departments.

At the beginning, monetary values were initially assigned to only certain SKUs with their unit prices provided by the Prime Contractor's planners. However, the Prime Contractor's superintendents (E&I and Mechanical) did not cooperate well in providing cost per unit during the entire audit. The superintendents stated at several instances to the researcher (Material Manager), that the roles of a planners were to assist the construction activities, and keeping inventories updated, like in manufacturing were not part of the scope of work for the project.

Due to the lack of cooperation by the Prime Contractor, too many unknown in terms of cost values for the various categories of materials, the researcher subsequently elected to abandon the accuracy value, in terms of monetary for the seventeen (17) material codes. Otherwise, the Action Research focused its findings on materials and equipment accuracies in terms of quantities and locations only.

4.2.4. Evaluation

The results of the audits conducted by the researcher (part of the CMT) are presented under two (2) tables: First, the researcher presents the accuracy results for the Electrical & Instrumentation's supplies in Table 4.8; and second, the results for the accuracies of Mechanical's supplies are illustrated in Table 4.9.

For further details on the Electrical & Instrumentation results as well as the Mechanical results, Appendices F1 to F17 demonstrated the contents for each department. In terms of measurement, the research expresses the results in terms of inaccuracies, which is the variance in error between the quantities reported by the Prime Contractor and the audit quantities recorded by the CMT. The researcher chose the variance of inaccuracy over accuracy because of its large percentage found in these audits.

Table 4. 8
Inventory Control – E&I

Electrical & Instrumentation Supplies - Unit Reporting										
Department	Yard	Code	Materials	No SKU	Contractor (Qty - Declared)	Contractor (Qty - Adjust)	Contractor (Qty - Real Qty)	CMT (Qty - On Hand)	Variance (Qty - items)	Inaccuarcy (%)
Electrical	Upper Laydown	1,1	Electrical Cables	44	29 634	-1 253	28 381	32 761	4 380	13,4%
Electrical	Sea Can Laydown	1,2	Electrical E&I Shack	99	0	0	0	8 000	8 000	100,0%
Electrical	Sea Can Laydown	1.3.1	Electrical Sea Can 1	578	0	0	0	72 237	72 237	100,0%
Electrical	Sea Can Laydown	1.3.2	Electrical Sea Can 2	241	0	0	0	63 354	63 354	100,0%
Electrical	Sea Can Laydown	1,4	Electrical Materials	163	2 305	(115)	2 190	3 357	1 167	34,8%
Electrical	Norseman Warehouse	1,5	Electrical Materials	109	925	(516)	409	450	41	9,1%
			Total	1234	32 864	(1 884)	30 980	180 159	149 179	82,8%
			Instrumentation	918	0	0	0	143 591	143 591	100,0%
			Electrical	316	32 864	(1 884)	30 980	36 568	5 588	15%

Dany Julien (2019)

Table 4. 9
Inventory Control – Mechanical

Mechanical Supplies - Unit Reporting										
Department	Yard	Code	Materials	No SKU	Contractor (Qty - Declared)	Contractor (Qty - Adjust)	Contractor (Qty - Real Qty)	CMT (Qty - On Hand)	Variance (Qty - items)	Inaccuarcy (Qty - %)
Mechanical	Norseman Warehouse	1.6	Pipe Fitting General	152	925	-516	409	450	41	9%
Mechanical	Norseman SeaCan	2.1	Copper Fittings	87	134	0	134	619	485	78%
Mechanical	Norseman SeaCan	2.2.1	CS Bare Fittings	277	2,828	-130	2,698	3,020	322	11%
Mechanical	Norseman SeaCan	2.2.2	CS Galvanized Fittings	100	740	-214	526	857	331	39%
Mechanical	Piping Laydown	2.2.4	CS Pipe	51	840	0	840	5,064	4,224	83%
Mechanical	Norseman SeaCan	2.3.1	FRP Fittings	101	608	-18	590	867	277	32%
Mechanical	Piping Laydown	2.3.2	FRP Pipe	111	0	0	0	1,840	1,840	100%
Mechanical	Norseman SeaCan	2.4.1	HDPE Fittings	218	605	-13	592	2,106	1,514	72%
Mechanical	Piping Laydown	2.4.2	HDPE Pipe	28	8,248	-8	8,240	9,828	1,588	16%
Mechanical	Norseman SeaCan	2.5.1	SS Fittings	292	2,636	-267	2,369	2,700	331	12%
Mechanical	Piping Laydown	2.5.2	SS Pipe	27	3,680	-280	3,400	4,127	727	18%
			Total	1444	21244	-1446	19798	31478	11680	37%

Dany Julien (2019)

The Prime Contractor's Instrumentation department did poorly in maintaining its inventories accurate. For instance, their materials and equipment were audited with the overall inaccuracy of 82.8% against the CMT's audit. In other words, less than 18% of the materials and equipment were reported accurately in quantities and by locations.

The E&I department, led by a unionized superintendent, who had a different view in operating a field versus the contractor's management team, practiced the philosophy of being at a site for achieving one main objective: to build a project, not to maintain inventories since resources weren't available for this task. Ironically, this job should have been executed by the Material Team, not by the E&I department.

Furthermore, the researcher notes that E&I department refused throughout the audit any attempt to improve the process of inventory management. Continuous improvement is in fact, prescribed in the Action Research methodology and described in the Action Research Cycle by Susman *et al*. (1978). For instance, the instrumentation staff in charge of managing high value materials located in the E&I shack (ref: code 1.2) and the two (2) sea containers (ref: code 1.3.1 and 1.3.2) chose not to account on-hand inventories for their materials and equipment at site. As a result, there were a total of only 918 non-recorded stock keeping units (SKU) versus 143,591 SKUs (instrumentation) recorded by CMT against the E&I shack (ref: code 1.2) and the two (2) sea containers (ref: code 1.3.1 and 1.3.2). For instance:

- When searching for materials due to be installed, the E&I crews operated with a process of walking, picking if available, and leaving with or without the materials from these locations (i.e. shack or sea containers). They were no pre-bagging of materials done ahead of the installation date;

- When removing materials from either of the three (3) locations, there was no tally recorded by the individuals on removing inventories or replacing it;

- If unavailable, the ordering of materials was made by one of the two (2) superintendent's planners. The researcher noted the ordering were made without a thorough check of all inventories available at site.

The Prime Contractor's Electrical department was better set-up than its counterpart in Instrumentation. Overall, the Electrical department (ref: code 1.1, 1.4, 1.5) had to manage 316 SKUs and had a total of 30,980 units (electrical) against the CMT's audit of 36,568 units. This performance accounted for an inaccuracy of 15%. In terms of materials per se, the electrical staffs which oversaw managing the electrical cables at one of the laydowns had also an inaccuracy of 13.4%. However, the electrical materials stored inside two (2) containers at the E&I laydown recorded a higher level of inaccuracy with 34.8%. The electrical staffs located at the Norseman Warehouse displayed the best performance in terms of inventory management. The audit demonstrated the lowest inaccuracy with a rating of 9.1%. The electrical results are illustrated in Table 4.8.

The performance of the Prime Contractor's Electrical & Instrumentation departments is in line with Construct no. 2 (Chapter One), which states that construction sites have fragmented supply chain processes. Overall, the Prime Contractor's Mechanical department applied better inventory management procedures than their counterparts in Electrical & Instrumentation. The Mechanical department had an inaccuracy of 37% when compared against the CMT's audit. The mechanical results are illustrated above in Table 4.9.

Like the E&I department, the mechanical staff working in the Norseman Warehouse displayed the best inaccuracy with 9% error versus the CMT's audit. On the other spectrum, the mechanical staff did not keep inventory for FRP Piping, showing an inaccuracy of 100% against the CMT's audit. Overall, the Prime Contractor's Mechanical department, like the E&I departments, fulfilled the Construct no. 2 (construction sites are managed with fragmented supply chain processes).

4.2.5. Conclusion – Inventory Control

The Prime Contractor did not commit itself in maintaining accurate inventory management, which included aspects such as controlling and overseeing ordering inventory, storage of inventory and controlling the amount of product to be bagged and installed. Simply put, the Prime Contractor did not always provide the right inventory, at the right quantity, in the right place, at the right time and at the optimal cost for its tradesmen team conducting field installation. Hence, lost time and increase costs were *de facto* for the Prime Contractor.

The researcher concluded that during the Action Research, the Prime Contractor was without a doubt, failing in keeping its general inventories accurate. Moreover, both Prime Contractor's departments (E&I and Mechanical) performed poorly in managing accurate inventories. The researcher concludes through its Action Research, that the Prime Contractor failed to take part in the methodology of improvement, and subsequently promoted non-necessary inventory surplus under a Time & Material contract.

- The Prime Contractor's Instrumentation department did poorly in maintaining inventories for their materials with an overall inaccuracy of 82.8% against the CMT's audit;
- The Prime Contractor's Electrical staff, although better than their counterpart in instrumentation, displayed a poor result with an inaccuracy of 15%;
- The Prime Contractor's Electrical & Instrumentation department fulfilled Construct no. 2, which states that construction sites are operated through a fragmented supply chain process;
- The Prime Contractor's Mechanical staffs maintained a better inventory than their counterpart in E&I, with an inaccuracy of 37% against the CMT's audit.

Finally, when comparing the performance of the Prime Contractor to the manufacturing industries, which will usually target a level of inventory accuracies in the range of six sigma (99.99966% - equate an error (inaccuracy) of 0.00034%), it is easy to state the Prime contractor's E&I and Mechanical departments don't operate on the same supply chain level of the manufacturing industries, with their inaccuracy level of 82.8% and 37% respectively.

4.3. SEMI-STRUCTURED INTERVIEWS

Following the initial review of literature, the results from the Participant Observation (level of supply chain activities in project management) and the Action Research (level of inventory inaccuracies), the enumeration of seven (7) constructs, and the application of various kernel theories related to construction mega-projects, the researcher opted for using the SCOR Model's framework, and enriched it, by adding some performance attributes and metrics related to engineering, procurement and construction management's activities during mega-projects.

This enriched SCOR Model became too large and had to be reduced in order to meet the research objectives. Thus, the researcher conducted a series of semi-structured interviews. The reduction gave the researcher a general view of performance attributes and metrics needed during mega-projects.

The semi-structured interviews were considered by the researcher as an exploratory work, which was required before conducting the final survey (artifact) for this research. Moreover, the semi-structured interviews are considered the building blocks for this thesis' artifact, whereas the survey presented in the following section, focus their findings on the optimal performance attributes and metrics that display the highest level of supply chain robustness, during certain types of contracts.

4.3.1. Interview Design

Prior to sending the interview by emails, the researcher tested the document with its thesis' director and two senior managers, which were co-workers at the mill upgrade project. There was three (3) revisions of the document comprising a) original, b) Rev1 and c) Rev2.1. Once sent, another modification to the interview document was brought, and was eventually renamed Rev2.2.

4.3.1.1. Original Interview

The original interview consists of the first draft document written by the researcher. The original interview is described in Appendix G1 for reference, and consists of the following items:

- The length of the interview was originally four (4) pages;
- In the first section, a basic section for participants' profile was introduced;
- The intend was to review the researcher's constructs with the participants;
- The knowledge of the SCOR Model was going to be tested with the participants;

- Eight (8) performance attributes were going to be presented to the participants, along with eleven (11) Level I metrics;
- Performance attributes, Level I and Level II metrics were then tested simultaneously against the five (5) project phases;
- The Level III metrics, which comprised of 360+ KPIs were not tested in the original interview, nor will it never be tested in the future.

4.3.1.2. Interview Revision 1

Interview Rev1 was presented to the thesis' director for critics, with the intent of receiving direction on how to conduct the interviews. Interview Rev1 is described in Appendix G2 for reference. The Interview Rev1 consists of the following items:

- The interview was lengthened from its original four (4) pages to a ten (10) pages document;
- The title of the interview was changed;
- A note requesting a Non-Disclosure Agreement (NDA) was introduced in the document;
- The researcher proposed the introduction of a Power Point document in order to familiarise the participants to the managerial problematic and the SCOR Model. The option of using a Power Point presentation was rejected. It was thought having a second document, beside the interviews, would have been too incumbent;
- Questions concerning the SCOR model were added to the interview;
- Questions relevant to the Construction Performance & Productivity Model were added to the interview for the first time;
- In the first section of the interview, a more detailed participants' profiles were added;
- The knowledge of supply chain functionality was also tested amongst the participants;
- Constructs, performance and productivity metrics were all tested with a Likert scale, and remark sections were also added for the participants to insert or state comments;

- The knowledge of the SCOR Model was also questioned as original version;
- One (1) performance attribute (Asset Management) was removed from the original document and replaced by Workers Management;
- Seven (7) performance attributes related to the SCOR Model were tested with a Likert scale, along with a space allocated for remarks;
- Proposal of introducing the SCOR definitions which are related to the performance attributes were inserted into the interview document;
- Proposal of introducing the CPPM definition to performance attributes along Level I and II metrics were also added to the interview document;
- CPPM's performance attributes, Level I and II metrics were tested against the five (5) phases of project management;
- Once again, the Level III metrics, which comprised of 360+ KPIs was not tested in these interviews.

4.3.1.3. Interview Revision 2.1

Interview Rev2.1 consisted of the final version of the interview document prior to its general sending by emails. At that time, the interview document had been modified based on several comments made by the thesis' director and two senior managers that were also co-workers with the researcher at a mega-project site. Interview Rev2.1 is described in Appendix G3 for reference. The Interview Rev2.1 consisted of the following activities:

- The interview was reduced to seven (7) pages;
- The final version of the title for the interview was agreed with the thesis' director;
- A Non-Disclosure Agreement (NDA) in the form of a Letter of Information and Consent form was written for the interview and for the up-coming survey. The Letter of Information and Consent is described in Appendix H and I for reference;
- The questions toward the participants' profiles were changed to reflect more a general view;

- Constructs, performance and productivity metrics were tested with a Likert scale, and a remark section was also added for the participants to insert comments;

- The knowledge of the SCOR Model was also tested amongst participants;

- Seven (7) performance attributes related to the proposed model (CPPM) were tested with a Likert scale;

- Definitions for each performance attributes were added in point-form format only;

- CPPM's performance attributes, Level I and II metrics were tested against the five (5) phases of project management;

- Level III metrics, which comprised of 360+ KPIs was not tested in these interviews but are presented in Appendix L1 to L7.

4.3.1.4. Interview Revision 2.2

Providing with flexibility of a semi-structured interview approach, the researcher was able to modify Interview Rev2.1 following immediate comment from participants regarding construction terminologies. The final interview version brought two (2) new changes and was named Interview Rev2.2. Interview Rev2.2 is described in Appendix G4 for reference, and include the following changes:

- The performance attribute named EPCM did consider at first, construction management into two (2) distinct functionalities: construction and management. Following participants comments on the first day after being sent, the researcher made the following change: the statement of EPCM (engineering, procurement, construction and management) was broken into EPCM (engineering, procurement and construction management);

- The researcher introduced the rating of not applicable (N/A) for the closed-out phase;

- The researcher introduced the rating of not applicable (N/A) for the performance attributes of project integration.

4.3.2. Participants

Emails were sent to potential participants which included a Letter of Invitation, a Letter of Consent and the semi-structured interviews. In the Letter of Invitation, participants were provided with a brief explanation of the purpose of the research. Examples for the document in mention above are found in the following appendices:

- Letter of Invitation. See Appendix H for reference;
- Letter of Information & Consent Form. See Appendix I for reference;
- Semi-Structured Interview_rev2.2. See Appendix G4 for reference.

Once the emails were forwarded to the participants, a period of approximately forty-eight (48) hours elapsed and the following steps were undertaken by the researcher:

- If the participants replied its willingness to take part in the interview, then telephone calls were set up and dates and time were arranged to conduct the interviews;
- If the participants did not reply, a second and a third email combined with one telephone call were made to incite a response into taking part in the interviews.

4.3.2.1. Acceptance Rate

There were in total thirty-eight (38) invitations sent to various senior engineering managers, construction managers and construction specialists. The invitation requested them to take part in first, the interviews, and leading to, second, a survey. From that number of invitations, twenty-eight (28) of these individuals accepted to take part in the interviews and survey. The acceptance rate accounted for 74%. Due to confidentiality, the names, emails, phone numbers and other credentials are not included in the appendices. Only the researcher and the Thesis Director have access to the personal information. The researcher presents in Table 4.10, the results of the acceptance rate.

Table 4. 10
Acceptance Response Rate

Acceptance Response Rate		
	No	
Interviews Request:	38	
Interviews Acceptance:	28	74%

Dany Julien (2019)

4.3.2.2. Participant Sampling

The sampling information for these twenty-eight (28) senior engineers, construction managers and construction specialists, which participated in the semi-structured interviews include the following profiles: (1) age group, (2) professional categories, (3) job positions, (4) job titles, (5) education, (6) locations, and (7) experience in E&C, (8) fields of specialisation, (9) trade certifications and (10) construction contracts.

4.3.2.3. Age Groups

- Age group no. 1, comprised of managers between the ages of 30 to 39 years of age. This group was the youngest one and is the least represented, which it made up 7% of the sampling population;

- Age group no. 2, comprised of managers between the ages of 40 to 49 years of age. This age group was the second most represented with 29% of the sampling population;

- Age group no. 3, comprised of managers between the ages of 50 to 59 years of age. This age group was the most represented with 49% of the sampling population;

- Age group no. 4, comprised of manager over 60+ years old, were the third largest group of the sampling population with 21%;

- Details data for the Age Group are tabulated in Appendix J and in Table 4.11, in accordance with the researcher's findings.

Table 4. 11
Participants' Age Group

Age Profile		
Age Group no. 1	(30-39)	7%
Age Group no. 2	(40-49)	29%
Age Group no. 3	(50-59)	43%
Age Group no. 4	(60+)	21%

Dany Julien (2019)

4.3.2.4. Professional Categories

- The largest group professionals were represented by the Construction Management Team with 54% of the sampling population;

- The professional group representing owners, such as engineers, were second in representation with 21% of the sampling population;

- The hybrid group, including managers representing contractors, CMT and/or owners represented the third most sampling population with 14%;

- Finally, contractors represented the least amount of the sampling population with 11%;

- Details data for the Professional Group are tabulated in Appendix J and in Table 4.12, in accordance with the researcher's findings.

Table 4. 12
Participants' Categories

Stackholder Profile	
Owner	21%
Construction	11%
Hybrid	14%
CMT	54%

Dany Julien (2019)

4.3.2.5. Job Positions

- Participants with the job position of Project Manager and Construction Manager were the most frequent positions, which accounted for eight (8) of the sampling participants or 28% overall;

- Health, Safety and Environment (HSE) positions came second overall with four (4) participants or 14% that took part

- in the interviews;

- Construction Specialists / Lead and Procurement / Logistics staffs are the third most frequent job positions amongst the sampling population with three (3) of each or 11% respectively.

- Details data for the Job Positions are tabulated in Appendix J and in Table 4.13, in accordance with the researcher's findings.

Table 4. 13
Job Positions

Job Positions		
Project Manager	6	21%
Construction Manager	2	7%
Project Control	2	7%
Safety	4	14%
Construction Specialist	3	11%
Contract	2	7%
Field Engineer	2	7%
Planning / Scheduling	2	7%
Procurement / Logistics	3	11%
Commissioning	1	4%
Performance	1	4%
Total	28	100%

Dany Julien (2019)

4.3.2.6. Job Titles

- A description of the job titles held by participants are described below in Table 4.14 and in Appendix J, in accordance with the researcher's findings;

- The job title of Manager is the most popular title held by participants, with fifteen (15) of the sampling population being a manager, or 54% in total.

Table 4. 14
Job Titles

Job Titles		
President	1	4%
Vice-President	2	7%
Manager	15	54%
Specilaists / Lead	9	32%
Consultant	1	4%
Total	28	100%

Dany Julien (2019)

4.3.2.7. Education

- The number of senior managers that held engineering vs. non-engineering degrees is described in Table 4.15 and in Appendix J, in accordance with the researcher's findings;

- Participants which had an engineering education accounted for thirteen (13) of the participants or 46% of the sampling population;

- In the same aspect, participants that have a non-engineering backgrounds amounted to fifteen (15) of them or 54% of the sampling population.

Table 4. 15
Background in Engineering Education

Engineering Education		
Engineers	13	46%
Non-Engineers	15	54%
Total	28	100%

Dany Julien (2019)

4.3.2.8. Geographical Locations

- The twenty-eight (28) participants that took part in the interviews came from three (3) countries: Canada (84%), France (8%) and USA (8%);

- Twenty-four (24) participants were from Canada and covered seven (7) provinces, of which nine (9) participants or 32% of the sampling population came from the western provinces, seven (7) participants or 25% were from Ontario, six (6) participants or 21% came from Quebec and two (2) participants or 8% were from the maritime provinces;

- Details data for the geographical locations are tabulated in Appendix J and in Table 4.16, as per the researcher's findings.

Table 4. 16
Geo-Locations of Participants

Locations of Participants

Country	Provinces / States		
Canada	British Columbia	3	11%
Canada	Alberta	2	7%
Canada	Saskatchewan	4	14%
Canada	Ontario	7	25%
Canada	Quebec	6	21%
Canada	New Brunswick	1	4%
Canada	Newfoundland	1	4%
France	Lyon	1	4%
France	Versailles	1	4%
USA	Florida	1	4%
USA	North Carolina	1	4%
	Total	28	100%

Dany Julien (2019)

4.3.2.9. Experience in E&C

- Appendix J and Table 4.17 illustrates the researcher's findings, with the years accumulated by participants that have worked in the engineering & construction (E&C) projects;

- Participants taking part in the interviews encompassed overall more than 648 years of cumulative experiences;

- Participants holding the job position of Project Manager were the most experience amongst all of them. Hence, in first place, Project Manager amounts to cumulative experiences of 138 years or 21%, followed by Safety Manager with 15% or ninety-nine (99) years, and Construction Specialists with 3% or eighty-five (85) years respectively;

- The participants that have the job positions of Construction Specialists have the highest average years of experience with 28.3 years (note: excluding the Commissioning and Performance participants with 30 and 40 years of experience);

- Following the Construction Specialists are the Safety and Construction Managers with 24.8 and 24.5 average years of experience.

Table 4. 17
Years of Experience in E&C

Job Positions	No.	Cum. Yrs Experience	Cum % Experience	Avg. Yrs Experience	Ranking
Project Manager	6	138	21%	23	6
Construction Manager	2	49	8%	25	5
Project Control	2	35	5%	18	9
Safety	4	99	15%	25	4
Construction Specialist	3	85	13%	28	3
Contract Manager	2	45	7%	23	7
Field Engineer	2	35	5%	18	9
Planning / Scheduling	2	40	6%	20	8
Procurement / Logistics	3	52	8%	17	10
Commissioning Manager	1	30	5%	30	2
Performance Manager	1	40	6%	40	1
	28	648	100%	23	

Dany Julien (2019)

4.3.2.10. Speciality Fields

- The researcher illustrates in Appendix J and Table 4.18 the years that participants have been working in their speciality fields. The years that are declared are related to their job title held during the interviews;

- Project Manager came first overall with the most cumulative years working in their fields with one-hundred and forty-five (145) years or 18% of the overall cumulative years for all participants;

- Safety staffs, Procurement /Logistics and Construction Specialists came second, third and fourth with 134, 115 and 110 years respectively, or in terms of percentage, 16%, 14% and 14% respectively;

- Excluding the Performance Manager which only accounted for one individual, the staffs comprising the Procurement / Logistics teams came second with an average of thirty-eight (38) years of experience in their fields, followed by the Construction Specialists with thirty-seven (37) years.

Table 4. 18
Years of Working in Speciality Fields

Job Positions	No.	Cum Yrs Field	Cum % Field	Avg. Yrs Field	Ranking
Project Manager	6	145	18%	24	9
Construction Manager	2	49	6%	25	8
Project Control	2	58	7%	29	6
Safety	4	134	16%	34	4
Construction Specialist	3	110	14%	37	3
Contract Manager	2	45	6%	23	10
Field Engineer	2	35	4%	18	11
Planning / Scheduling	2	52	6%	26	7
Procurement / Logistics	3	115	14%	38	2
Commissioning Manager	1	30	4%	30	5
Performance Manager	1	40	5%	40	1
	28	813	100%	29	

Dany Julien (2019)

4.3.2.11. Trade Certifications

- The researcher illustrates in Appendix J and Table 4.19 the number of participants that held at least one trade certification (i.e. millwright, pipe fitter, electrician, etc.);

- 50% of the participants that took part in the interviews held some sort of trade tickets such as: a) electrician, master electrician and instrumentation technician; b) heavy machinery operator, farming machinery operator, c) pressure welder and pipefitter, d) power engineer, e) trucking operator, and f) roughneck;

- 100% of the participants that held the job positions as Construction Specialists, Planning & Scheduling, Commissioning Manager and Performance Manager were held by staffs that had at least a trade certificate;

- None of the participant that held the job positions of Contract Manager and Field Engineer had a trade certificate.

Table 4. 19
Participants Holding Trade Certificates

Participants Holding a Trade Certificate

Job Positions	No.	Yes	No	Cum % Trade
Project Manager	6	1	5	17%
Construction Manager	2	1	1	50%
Project Control	2	1	1	50%
Safety	4	2	2	50%
Construction Specialist	3	3	0	100%
Contract Manager	2	0	2	0%
Field Engineer	2	0	2	0%
Planning / Scheduling	2	2	0	100%
Procurement / Logistics	3	2	1	67%
Commissioning Manager	1	1	0	100%
Performance Manager	1	1	0	100%
	28	14	14	50%

Dany Julien (2019)

4.3.2.12. Construction Contracts

This section describes the amount of years that participants had been working under either a) Lump Sum contracts (Design + Built contracts) or b) Time & Materials contracts (Cost + % contracts). The researcher illustrated in Table 4.20 the years and percentage between Lump Sum contracts and Time & Materials contracts, which participants had worked under. The results of contractual experience amongst the participants with Lump Sum contracts are as followed:

- The Planning / Scheduling staffs had the most experience in Lump Sum contracts with an average of fifteen (15) years, followed in second by Procurement / Logistics staff with fourteen (14) years, and in third with Project Manager and Safety staffs with eleven (11) years respectively;
- 40% of the participants had primarily experienced in Lump Sum contracts.

The results of contractual experience amongst the participants with Time & Materials contracts are as followed:

- Excluding the Performance Manager and Commissioning Manager whom had forty (40) and twenty-four (24) years respectively in dealing with Time & Materials contracts, Construction Specialists finished third with eighteen (18) years of experience, followed in fourth position with Construction Managers whom had seventeen (17) years of experience;

- 60% of the participants had construction contracts' experiences under Time & Materials;

- It is noted in this thesis, the researcher only interviewed one performance manager with forty (40) years of employment, of which all of its time were spent under Time & Materials contracts. This simple correlation makes sense, since protecting the project owners' interests is at the highest importance during Time & Materials contracts, and it is in the owners' interests to hire performance managers.

Table 4. 20
Years of Experience with Construction Contracts

Year of Experience in Construction Contracts									
				Lump Sum Contract (Design+Build Contract)			Time & Materials Contract (Cost+% Contract		
Job Positions	No.	Cum. Yrs Experience E&C	Avg. Yrs Experience E&C	Cum % LSC	Avg. Yrs LSC	Ranking	Cum % T&M	Avg. Yrs T&M	Ranking
Project Manager	6	138	23	47%	11	3	53%	12	6
Construction Manager	2	49	25	30%	7	6	70%	17	4
Project Control	2	35	18	18%	3	8	83%	14	5
Safety	4	99	25	44%	11	3	56%	14	5
Construction Specialist	3	85	28	37%	10	4	63%	18	3
Contract Manager	2	45	23	38%	8	5	63%	14	5
Field Engineer	2	35	18	45%	8	5	55%	10	7
Planning / Scheduling	2	40	20	75%	15	1	25%	5	8
Procurement / Logistics	3	52	17	83%	14	2	17%	3	9
Commissioning Manager	1	30	30	20%	6	7	80%	24	2
Performance Manager	1	40	40	0%	0	9	100%	40	1
	28	648	23	40%	9		60%	16	

Dany Julien (2019)

In conclusion, the participants for this research were generally above forty (40) years old, and their nationalities primarily composed of 78% of Canadian, which amongst them, 46% had engineering degrees. Management positions including managers, construction specialists and leads accounted for 86% of the sampling population. Participants with the title of Project Manager had the most years of experience with 145 years. Finally, a larger part (60%) of participants had worked under Time & Material contracts, with the remaining 40% of them having more Lump Sum contracts experiences.

4.3.3. Types of Interviews

For each participant whom replied positively at taking part in the interviews, the researcher informed them to allocate a period of approximately forty-five (45) minutes, in order to conduct the interview by either phone, face-to-face or Skype. Once all interviews completed, the length of the interviews conducted with the participants were:

- A total of twenty-eight (28) hours and fifty-eight (58) minutes was spent by the researcher in conducting twenty-eight (28) interviews;
- The shortest interview took thirty-two (32) minutes to conduct;
- The longest interview took one (1) hour and twenty-five (25) minutes to complete;
- The average time to conduct one (1) interview was one (1) hour and two (2) minutes, which was seventeen (17) more minutes than forecasted at forty-five (45) minutes;
- The researcher describes in Table 4.21 the amount of time which participants took to perform the interview.

Table 4. 21
Time Conducting the Interviews

Time Conducting the Interviews	
Total Hours Spent in Conducting 28 Interviews	28h 58min
Shortest Time for One Interview	32 min
Longest Time for One Interview	1h 25min
Average Time for Conducting One Interview	1h 02min

Dany Julien (2019)

The participants (contractors, engineers, construction managers, etc.) provided their verbal answers and the interviewer (researcher) recorded them with their remarks directly on the interview document pertaining to each of them. Examples of semi-structured interviews along with their hand-written remarks are provided in Appendix M for reference. The researcher illustrates in Table 4.22 the types of semi-structured interviews that were conducted for all of twenty-eight (28) participants.

Table 4. 22
Types of Interviews

Types of Interviews		
Face-to-Face / In person	5	18%
Telephone	22	79%
Skype / FaceTime	1	4%
Total	28	100%

Dany Julien (2019)

4.3.4. Constructs Results

The results obtained during the semi-structured interviews are detailed in this section, along with the correlation with the constructs emitted in Chapter One and some of the theoretical concepts that are presented in Chapter Two. Overall, there were 168 answers provided by the participants during the interviews.

4.3.4.1. Manufacturing vs Construction

Each question for this section is coded as Note 1, Note 2, Note 3, Note 4, Note 5 and Note 6. The researcher illustrates in Table 4.23, six (6) questions and their quantitative relations between manufacturing and construction activities.

Table 4. 23
Manufacturing vs. Construction

	Manufacturing vs Construction	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
		1	**2**	**3**	**4**	**5**	**Total**
1	Construction projects are unique, non-routine and non-repetitive.	0	8	3	14	3	**28**
		0%	**29%**	**11%**	**50%**	**11%**	**100%**
2	In mining and O&G projects, replication of activities are hard to implement.	1	14	2	11	0	**28**
		4%	**50%**	**7%**	**39%**	**0%**	**100%**
3	In shipyard projects, replication of activities would be easier to implement.	0	1	1	22	4	**28**
		0%	**4%**	**4%**	**79%**	**14%**	**100%**
4	Manufacturing processes are highly automated, whereas construction processes are human-driven.	0	1	0,5	17,5	9	**28**
		0%	**4%**	**2%**	**63%**	**32%**	**100%**
5	Bill of Materials (BOM) is controlled in manufacturing, whereas BOM in construction constantly evolve and change.	0	5	5,5	14,5	3	**28**
		0%	**18%**	**20%**	**52%**	**11%**	**100%**
6	Information technology in manufacturing is homogenous and powerful, whereas IT in construction is heterogenous and weak.	0	3	2	19	4	**28**
		0%	**11%**	**7%**	**68%**	**14%**	**100%**
		1	**32**	**14**	**98**	**23**	**168**

Dany Julien (2019)

Note 1a: 61% of participants that took part in the interviews agreed or strongly agreed that construction projects are unique and non-routine. This statement is important for the purpose of implementing supply chain process in a manufacturing way is impeded by the project uniqueness.

Note 1b: 40% of other participants that took part in the interviews taught that projects were not so unique and that they could be routine and repetitive. This level of disagreement stem for a new construction approach in modular building which offer repetitiveness in building processes. The researcher enumerates in Table 4.24 the various comments made by the participants between manufacturing and construction.

Table 4. 24
Participants' Remarks: Interview Question 1a-1b

Likert Scale	<u>Participants Comments</u> ❖ **Construction projects are unique, non-routine and non-repetitive.**
1. Strongly Disagree	
2. Disagree	- Projects are complex but feasible to repetition. - Although unique, some projects activities can be repetitive. - Routine can be implemented. Projects are unique and repetitive. - To some extent while they are unique to a company, project can be repetitive to a contractor. - Projects are always repetitive, otherwise trades could not perform their trades. - Road paving, civil works, are repetitive. - Project are unique, routine and repetitive.
3. Undecided	- Trades like scaffolding and welding are tasks-repetitive. - Projects as a whole may be different but tradesmen accomplish the same tasks over and over. - Projects are unique but not routine. - Routine can be implemented. - Civil works are repetitive.
4. Agree	- Modular projects, like camp housing projects in construction will repeat themselves. - Projects are all unique, no matter how similar they are. - Every day, something different. - Hard to plan because we decide to keep that way. - Not every piece of a pipe is the same. - Replication is possible in boiler making jobs. Experience in Fort Mac. - Projects are usually one off a kind and different locations.
5. Strongly Agree	

Dany Julien (2019)

Note 2a: Only 39% of the participants that took part in the interviews agreed in the statement that replication of activities in mining and oil & gas are hard to implement.

Note 2b: 61% of the participants that took part in the interviews strongly disagreed, disagreed or were undecided in the statement that replication of activities in mining and oil & gas are hard to implement. This high percentage of agreement for this statement is due to the more popular concept of modular building over the recent years, and the duplication of functionalities (i.e. piping project) within the same project. The researcher enumerates in Table 4.25 various comments made by the participants between manufacturing and construction.

Table 4. 25
Participants' Remarks: Interview Question 2a-2b

Likert Scale	Participants Comments ❖ Mining and O&G projects, replication of activities are hard to implement.
1. Strongly Disagree	- Changing project scales, still activities remain repetitive. - Activities are not hard to replicate. Piping projects in O&G are often replicated from station to station.
2. Disagree	- Piping are often repetitive. - Field activities are non-repetitive whereas modular activities are repetitive. - It can be done. Produce a library to install repetitive activities. Implement schedule confidence. - Standardize activities in O&G are common. - Must clearly identify inner manufacturing-like process. - Bad planning. Must apply manufacturing protocols. - Power station are very similar from project to project. - Drilling and blasting are very similar from project to project. - Shaft sinking are cyclicals and repetitive. - Prefab modular building are easy to implement. - Experience in building five stations, all the same. - Experience in building plate steel fabrication for two vessels. - Crushing, sizing and machinery installation are the same process.
3. Undecided	- Same planning, different processes.
4. Agree	- Lack of coordination and planning. Project managers have different ways to doing things. - If well planned, you can replicate activities. 70% of activities can be repeated. - Build three similar plants. Lesson learned are to make it different each time to achieve better product. Similar building and different planning. - Some teams will oppose to the way you are building it. - Very general statement. It depends on trade. Replication of processes are hard to implement.
5. Strongly Agree	- O&G is highly repetitive.

Dany Julien (2019)

Note 3a: 93% of the participants that took part in the interviews agreed or strongly agreed in the statement that replication of activities in shipyards are easier to implement, based on the scope of shipyard works, reproducing the same design over and over, or similarities in designs from project to project.

Note 3b: 8% of the participants that took part in the interviews disagreed or were undecided in the statement that replication of activities in shipyards are easier to implement. The researcher enumerates in Table 4.26 various comments made by the participants between manufacturing and construction.

Table 4. 26
Participants' Remarks: Interview Question 3a-3b

Likert Scale	**Participants Comments** ❖ **In shipyard projects, replication of activities would be easier to implement.**
1. Strongly Disagree	
2. Disagree	
3. Undecided	- Welding in shipyard is very repetitive. Weld seems all day.
4. Agree	- Stick build and modular building can be repeated much easier in shipyards. - Material control is easier to keep track. - Prototype is costly to set-up but afterward, you can replicate activities.
5. Strongly Agree	

Dany Julien (2019)

Note 4a: 94% of the participant that took part in the interviews agreed or strongly agreed that manufacturing processes are highly automated, boosted by powerful software which control supply chain networks from a to z; whereas construction processes are human-driven, less controlled, less cartesian and more flexible in bringing changes in order to adapt to the current needs.

Note 4b: 6% of the participant that took part in the interviews disagreed or were undecided toward the statement that manufacturing processes are highly automated, whereas construction processes are human-driven. The researcher enumerates in Table 4.27 the various comments made by the participants between manufacturing and construction.

Table 4. 27
Participants' Remarks: Interview Question 4a-4b

Likert Scale	**Participants Comments** ❖ **Manufacturing processes are highly automated, whereas construction processes are human-driven.**
1. Strongly Disagree	
2. Disagree	- People make it hard for nothing. There is opportunity to automate.
3. Undecided	
4. Agree	- There are automation in construction (modular welding) but overall not as advanced as in manufacturing. - Stick build project (O&G) such as framing are automated. - Manufacturing can be human-driven too. - Gate technologies (process) for tracking. - Hard to accomplish in the field. Piping/pipe shop is easier to do. - Manufacturing have better collaboration between owners and suppliers.
5. Strongly Agree	

Dany Julien (2019)

Note 5a: 63% of the participants that took part in the interviews agreed or strongly agreed toward the concept that flow of materials (Bills of Materials - BOM) is better controlled in manufacturing, due to the more predictable environment; whereas BOM in construction activities constantly evolve and change, due to the design, planning and scheduling changes that can be affected by several factors such as the weather, lack of materials, drawing revision, etc.

Note 5b: 38% of the participants that took part in the interviews disagreed or were undecided toward the concept that flow of material (Bills of Materials - BOM) is controlled in manufacturing; whereas BOM in construction activities constantly evolve and change. These participants thought that although changes do occur in construction project, BOM are still pretty much forecastable. The researcher enumerates in Table 4.28 various comments made by the participants between manufacturing and construction.

Table 4. 28
Participants' Remarks: Interview Question 5a-5b

Likert Scale	Participants Comments ❖ **Flow of materials (BOM) is controlled in manufacturing, whereas BOM in construction constantly evolved and changes.**
1. Strongly Disagree	
2. Disagree	- It is feasible to predict BOM in construction. Poor excuses and execution from contractors. - Poor planning is the cause and shouldn't happen if done before execution. - Drawing specification and changes are very important. - Projects don't take level of engineering and planning high enough. - If engineering and drawings are done correctly, BOM should be accurate in the first place, and little changes will follow.
3. Undecided	- Manufacturing have tremendous logistics access. Construction site have poor logistics. It is very problematic. - BOM is good at job site. - BOM don't always change. Suncor had several project at the same place. - Bridge project – unique, one time source.
4. Agree	- Projects are never implemented universally. - Change orders make it hard to maintain constant schedule. - Lack of details, communication and lack of proximity. - Change orders, RFI, Scope changes affect schedules and BOM. - Changes from project to project.
5. Strongly Agree	

Dany Julien (2019)

Note 6a: 82% of the participants that took part in the interviews agreed or strongly agreed in the statement that information technology in the manufacturing industry is more transparent, more homogeneous and more powerful than the integration of information technology in the construction industry. In fact, the researcher observed several IT platforms operating by several contractors, all in a silo approach with little integration between them.

Note 6b: 18% of the participants that took part in the interviews disagreed or were undecided towards the statement that information technology in the manufacturing industry is more transparent, more homogeneous and more powerful than the integration information technology in the construction industry. These participants generally didn't think the need for a centralised IT system, since each contractor operated independently. The researcher enumerates in Table 4.29 the various comments made by the participants between manufacturing and construction.

Table 4. 29
Participants' Remarks: Interview Question 6a-6b

Likert Scale	Participants Comments ❖ **Information technology in manufacturing is homogenous and powerful, whereas IT in construction is heterogeneous and weak.**
1. Strongly Disagree	
2. Disagree	- It should not be an excuse for poor productivity. - It can be done but only in isolated department. Can't be done across the board. - The construction industry is more and more standardized,
3. Undecided	- The construction industry is changing.
4. Agree	- Billions dollars projects are often built on Excel spreadsheet - Owners don't want to spend money on IT integration for one project only. - There are no sharing of information technology at site. Big Brother is watching syndrome. - General contractors often don't have all the information. - EPCM don't want to invest in one system. Owners will end up paying for it anyway. - Big Brother is watching you syndrome. Several contractors and owner on same SAP platforms, however, no data interchange between them. - IT in construction is not constant amongst discipline and phases.
5. Strongly Agree	- The costs are never part of the bid package. Owners try to squeeze every penny in projects. Poor IT integration ends up costing more to owners. - Manufacturing is highly automated. Welding is human-driven. - Robotics / automation is important in manufacturing, not so in construction.

Dany Julien (2019)

4.3.4.2. Construction Constructs

The researcher illustrates in Table 4.30 the correlations amongst the construction constructs that are stated in Chapter One. Overall, there were 196 answers provided by the participants during the interviews. Each question for this topic is coded in the semis-structured interviews as Note 7, Note 8, Note 9, Note 10, Note 11, Note 12 and Note 13.

Table 4. 30
Construction Constructs

	Construction Constructs	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
		1	2	3	4	5	Total
7	Construction is not manufacturing, hence supply chain efficiency will never be achieved.	3	17	2	5	1	28
		11%	61%	7%	18%	4%	100%
8	Supply chain processes "as understood in most industries"are seen as "fragmented" in the construction industry.	0	3	2	21	2	28
		0%	11%	7%	75%	7%	100%
9	Project management techniques (ie. PMI) are homogeneous, in a sense, that PM and CM utilise similar approaches / techniques from project to project.	0	4	0,5	22,5	1	28
		0%	14%	2%	80%	4%	100%
10	Status quo in the construction industry: The construction industry takes longer time to adopt new processes and technologies.	0	2	2	21	3	28
		0%	7%	7%	75%	11%	100%
11	Progress reporting are reported on a macro-level. Manpower is not available to implement detailed statistical or analytical reportings.	0	4	3	20	1	28
		0%	14%	11%	71%	4%	100%
12	In construction, changes are always viewed as costly.	0	2	0	16	10	28
		0%	7%	0%	57%	36%	100%
13	Uncertainties are common in mega-projects.	0	1	4,5	13,5	9	28
		0%	4%	16%	48%	32%	100%
		3	33	14	119	27	196

Dany Julien (2019)

Note 7a: 22% of the participants that took part in the interviews agreed or strongly agreed in the statement that supply chain efficiency will never be achieved in construction mega-projects.

Note 7b: 78% of the participants that took part in the interviews believed (strongly disagreed, disagreed, undecided) that supply chain efficiency can be achieved in construction mega-projects. The participants understood that projects are unique, but there is no excuse to improve the supply chain processes during mega-projects. The researcher enumerates in Table 4.31 various comments made by the participants regarding the construction constructs put forward in this research.

Table 4. 31
Participants' Remarks for Interview Question 7a-7b

Likert Scale	Participants Comments ❖ **Construction is not manufacturing, hence, supply chain efficiency will never be achieved.**
1. Strongly Disagree	- Sequencing is feasible in construction. - Some level of supply chain efficiency can be achieved in construction. - May not be the level of manufacturing, but there is room for improvement.
2. Disagree	- Construction can implement its process to improve efficiencies. There is no reason not to be successful. - Evolved around good planning. - Will never meet the manufacturing levels, but construction has room to improve. - Planning in construction. Better way to plan. Current culture in engineering. - Construction has room for supply chain improvement. - There is no reason for achieving supply chain to be achieved. - There is a possibility to have supply chain efficiencies. Construction may not attain manufacturing level but there are ways to improve supply chain levels. - Supply chain efficiencies can be improved. - Construction is one shot deal. Can be repetitive. - Over a period of time, construction will improve. - There is a will to make it happen. - Supply chain efficiency in construction can be achieved. - Supply chain may not be at the same level of manufacturing but it can be improved. - Supply chain efficiency is possible in construction.
3. Undecided	- Supply chain can be improved in construction. There is a strong opportunity in construction. - Supply chain efficiency can be gained, but will never be like manufacturing as it is not automated.
4. Agree	- Engineering changes make it hard to reach a supply chain. - High cost to implement. - Every construction project has its uniqueness. The better contractors will have it in place.
5. Strongly Agree	

Dany Julien (2019)

Note 8a: Although the participants that took part in the interviews believe that supply chain efficiency can be achieved (Note 7b) in construction mega-projects, 84% of these participants agreed or strongly agreed that supply chain processes are fragmented.

Note 8b: 18% of the participants that took part in the interviews disagreed or were undecided against the statement that supply chain processes in construction were fragmented. The researcher enumerates in Table 4.32 various comments made by the participants regarding the construction constructs put forward in this research.

Table 4. 32
Participants' Remarks: Interview Question 8a-8b

Likert Scale	**Participants Comments** ❖ **Supply chain processes as understood in most industries are seen as fragmented in the construction industry.**
1. Strongly Disagree	
2. Disagree	- Evolved around good planning. - Warehousing (materials) bagging is not fragmented in construction.
3. Undecided	
4. Agree	- There is so many middle lines negotiating. - Need to stream down procurement processes. - What you plan before construction makes it different in supply chain efficiencies. - Everything can go side way. Project scope can change overnight due to test failure. Process has to be changed. - There is a lack of coordination and collaboration. - Manufacturing is repetitive and large and constant orders are common. In construction, projects are unique, and orders and small and changing often.
5. Strongly Agree	- Construction has a different approach to supply chain.

Dany Julien (2019)

Note 9a: 84% of the participants that took part in the interviews agreed or strongly agreed in which the project management techniques, such as the one formulated by PMI, are applied homogeneously from projects to projects.

Note 9b: 16% of the participants that took part in the interviews disagreed or were undecided in stating that project management techniques, such as the one formulated by PMI, are not applied homogeneously from project to project. Moreover, these participants believe that project managers will adapt their project management techniques to each specific project. The researcher enumerates in Table 4.33 various comments made by the participants regarding the construction constructs put forward in this thesis.

Table 4. 33
Participants' Remarks: Interview Question 9a-9b

Likert Scale	Participants Comments ❖ **Project management techniques (e.g.: PMI) are homogenous in a sense that PM and CM utilise similar approaches / techniques from project to project.**
1. Strongly Disagree	
2. Disagree	- Lots of time, construction managers are already working in a sealed box that can be changed. - There is a lack of project standards in the field. Need to obtain another level of standard and action in the fields.
3. Undecided	- Usually, it's the fault of the owner, as they try to save money, they don't want to pay for constructability process until the near end of the planning phase. - Every project manager has his/her way of doing thing, has his/her idea.
4. Agree	- Ideally it should be homogeneous but reality, project are not. - Project manager may have the same approach. The difference is how it gets implemented. - PMI (PMBOK) is a tool, not a process. - Follow the same principle. - Project management is like learning a new language for each mega-project. - Project management is supposed to be that way. Processes are supposed to be adaptable. Project manager and construction manager only use them to suit their needs for each unique project. - Project manager don't use all 100% process for every project.
5. Strongly Agree	

Dany Julien (2019)

Note 10a: 86% of the participants that took part in the interviews agreed or strongly agreed in the statement that suggest the construction industry is keeping a modus operandi-status quo when comes the time to adopt new processes and technologies during construction mega-projects. However, the participants did not oppose to keeping *status quo* as long as projects were completed on time and on schedule.

Note 10b: 14% of the participants that took part in the interviews disagreed or were undecided in the statement that construction industry held a status quo in regards to adopting new processes and technologies. The researcher enumerates in Table 4.34 various comments made by the participants regarding the construction constructs put forward in this research.

Table 4. 34
Participants' Remarks: Interview Question 10a-10b

Likert Scale	Participants Comments ❖ **Status quo in the construction industry. The construction industry takes longer time to adopt new processes and technologies.**
1. Strongly Disagree	
2. Disagree	
3. Undecided	- Construction culture is changing.
4. Agree	- Larger O&G projects are 20 years ahead of mining projects when considering IT integration. - Construction is a strong culture. - Nepotism of good planning. - We let contractors on clouds for innovation. In North America, we don't seem to learn lessons of the past, In England, for instance, quantity surveyor have a book on BOM. Everyone bids on the same standard. - Clients see organisation and complexity of the project as a risk. - It's a construction mindset and generational. - The basic information technology in construction is very weak.
5. Strongly Agree	- If it is not broken it, don't fix it. - Lots of people wants to retire in their jobs. - The construction is still stuck in the past.

Dany Julien (2019)

Note 11a: 75% of the participants that took part in the interviews agreed or strongly agreed towards progress reporting in construction mega-projects are often reported at a macro-level. The participants realised that a construction team doesn't have the same amount of manpower or sophisticated software, when compared to manufacturing's larger resources in office management and integrated ERP.

Note 11b: 25% of the participants that took part in the interviews disagreed or were undecided about the level of detailed reporting during construction mega-projects. In other words, these participants believed the level of reporting found in their progress reports was sufficiently detailed, and it was not necessary to implement other fancy statistical or analytical reporting. The researcher enumerated in Table 4.35 various comments made by the participants regarding the construction constructs put forward in this research.

Table 4. 35
Participants' Remarks: Interview Question 11a-11b

Likert Scale	Participants Comments ❖ **Progress reporting are reported on a macro-level. Manpower is not available to implement detailed statistics / analytics reporting.**
1. Strongly Disagree	
2. Disagree	- Data is available but you don't have to treat it. Don't use the data on your advantage. - Detail reporting is the least interest in construction. - It's not a question of manpower to commit to detail reporting, it's the lack of management commitment.
3. Undecided	- The more homogeneous a project is, the better data you get. - More repetitive a project, the better data you get.
4. Agree	- The capabilities is there. - The granularity is an effort to make it available. - Performance manager should be imbedded in the projet. - Reporting is about quarterly reporting, not daily or weekly reporting. - Management ratio is always kept to the lowest possible. Very little fat allowed by owners. - O&G uses program like PRISM. - In construction, management is not willing to hire performance analyst. - Construction management is focus on getting the job done, not doing analyst. - There is no performance manager because there is no funds available. - Too thin (not enough staffs) in the office. - It's a competency issue. - It is not integrated but the effort from management is there. - Manufacturing is highly robotics. They can provide detailed reporting. - If you start to report at a micro-level, you will delay progress.
5. Strongly Agree	- In manufacturing, real-time reporting to their employees is essential. In construction management, employees are often left in the dark.

Dany Julien (2019)

Note 12a: 93% percent of the participants that took part in the interviews agreed or strongly agreed in the statement that introducing changes are always viewed as costly.

Note 12b: 7% of the participants that took part in the interviews disagreed in the statement that changes were always viewed as costly. In fact, these participants believed that very often, changes can be positive and if applied right, can bring savings to a project. The researcher enumerates in Table 4.36 various comments made by the participants regarding the construction constructs put forward in this research.

Table 4. 36
Participants' Remarks: Interview Question 12a-12b

Likert Scale	Participants Comments ❖ **In construction, changes are always seen as costly.**
1. Strongly Disagree	
2. Disagree	- Most chaos in created by bad contract agreements, which any general contractor will take advantage of it.
3. Undecided	- Changes are not always costly.
4. Agree	- Sometimes changes is saving. - Chaos is cash for contractors and engineering firms. - Nobody wants to rock the boat. - It's a major road block in construction. - Should build-to-design and assuming design is correct. - Engineering firms enjoy designing it twice, to collect change order revenues. - When contractors control the change (e.g. EPC contracts), the changes are always more costly.
5. Strongly Agree	- It is not the right. People always believes that it is always costly, but it's wrong. - If engineering drawings are done, it should be no problems. - Change management is common thing in construction. - Change is viewed as costly by contractors and trades only. Changes mean more revenues.

Dany Julien (2019)

Note 13a: 80% of the participants that took part in the interviews agreed or strongly agreed in the statement that uncertainty was common in mega-projects. Participants understood that at no time, will 100% of the engineering drawings be ready at the beginning of a mega-project. Thus, uncertainty is imminent, common and expected during a mega-project.

Note 13b: 20% of the participants that took part in the interviews disagreed or were undecided in the statement that uncertainty was common in mega-projects. These participants did not associate uncertainty with the drawings not being completed at hundred (100%) percent before the execution of the project, as they see this approach as a standard in the construction industry. These participants also regarded change orders, Request for Information (RFI) and other inquiries as standard in the construction industry. The researcher enumerates in Table 4.37 various comments made by the participants regarding the construction constructs put forward in this research.

Table 4. 37
Participants' Remarks: Interview Question 13a-13b

Likert Scale	Participants Comments ❖ Uncertainties are common in mega-projects.
1. Strongly Disagree	
2. Disagree	- In mega-project, even though a project is completed, it is not finished.
3. Undecided	- Uncertainties is not always common in construction.
4. Agree	- We will deal with it when we get there. - If planning is done properly, uncertainties doesn't happen. - Poor planning and don't consider the cost of safety. - Project in BC (Dam C), in NFLD (Muskrat Falls) and Alberta (OLG) are prime examples. - Trying to run with some levels of organisation. - Harsh weather can create uncertainties. - Risk assessment with alternative options: critical status, red or green. - Due to a lack of experience of knowledge. - Due to engineering drawing being incomplete. - The problem with mega-projects is the duration. - Uncertainties tend to be created in cycle period. For instance, O&G industries, when the market price of petroleum is high, the O&G companies rush into projects in the same time, causing chaos, laxness, and create massive market fluctuation. - Uncertainty and chaos is due to lack of planning during the detailed planning phases.
5. Strongly Agree	- Chaos is cash. More uncertainties, more revenues for trades and contractors.

Dany Julien (2019)

4.3.4.3. Construction Productivity

The researcher illustrates in Table 4.38 statement of construction productivity that are stated in Chapter One and Chapter Two. Overall, there were 196 answers provided by the participants during the interviews. Each question for this topic is coded as Note 14, Note 15, Note 16, and Note 17.

Table 4. 38
Participants' Remarks: Construction Productivity

	Construction Productivity	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
		1	2	3	4	5	Total
14	Large majorities (>51%) of mega-projects suffer cost overruns.	0	0	1,5	13,5	13	28
		0%	0%	5%	48%	46%	100%
15	Large majorities (>51%) of mega-projects report late completion.	0	1	0	13	14	28
		0%	4%	0%	46%	50%	100%
16	Over the last 20 years, Annual Productivity Growth (APG) in construction has only increased 1%, well below the manufactring APG (3.6%).	1	0	4	19	4	28
		4%	0%	14%	68%	14%	100%
17	Some accounting / research firms claim that construction indusry could improve 5-10x its productivity boost by moving to some (not all) of its processes to a manufacturing-style production system.	2	12	4	9	1	28
		7%	43%	14%	32%	4%	100%
		3	13	9,5	54,5	32	112

Dany Julien (2019)

Note 14a: 95% of the participants that took part in the interviews agreed or strongly agreed that mega-projects were bounded to suffer cost overruns.

Note 14b: 5% of the participants that took part in the interviews were undecided in cost overruns. The researcher illustrates in Table 4.39 various comments made by the participants regarding the construction productivity.

Table 4. 39
Participants' Remarks: Interview Question 14a-14b

Likert Scale	Participants Comments
1. Strongly Disagree	
2. Disagree	
3. Undecided	- Depends on competency of the construction management team and project management team.
4. Agree	- Public perception on project decisions often affect management and the project costs. - Clients often change the scope of work during the project.
5. Strongly Agree	

Dany Julien (2019)

Note 15a: 96% of the participants that took part in the interviews agreed or strongly agreed that mega-projects were completed late.

Note 15b: 4% of the participants that took part in the interviews disagreed that projects were being completed late. The researcher enumerates in Table 4.40 various comments made by the participants regarding the construction productivity.

Table 4. 40
Participants' Remarks: Interview Question 15a-15b

Likert Scale	Participants Comments
1. Strongly Disagree	
2. Disagree	
3. Undecided	
4. Agree	- Late completion is communication dependent. - Cause by scope emission, causing scope creep in construction.
5. Strongly Agree	- Different factors for completing late. It has become the standard industry. - The bigger the project, the later it is completed.

Dany Julien (2019)

Note 16a: 82% of the participants that took part in the interviews agreed or strongly agreed that construction's Annual Productivity Growth (APG) has only increased by 1% over the last twenty (20) years, whereas the manufacturing' APG has enjoyed a 3% growth over the same period.

Note 16b: 14% of the participants that took part in the interviews were undecided with the statement that construction's APG has only increased by 1% over the last twenty (20) years. Their disagreements stem on the fact that no one knew for sure what was an APG. The researcher enumerates in Table 4.41 the various comments made by the participants regarding the construction productivity.

Table 4. 41
Participants' Remark: Interview Question 16a-16b

Likert Scale	Participants Comments
1. Strongly Disagree	- Construction technologies have change. Productivity in construction is hard to measure.
2. Disagree	-
3. Undecided	-
4. Agree	- Still using last generation technology too often, like Excel. - Construction projects deals with too many unions, planning is weak. - Manufacturing should be higher than 3.6%. - Manufacturing deals with one union, construction project deals with large amount of unions. Moreover, unions will battle amongst themselves for more control of manpower. - Construction industry doesn't have advanced technologies. Manufacturing is automated.
5. Strongly Agree	

Dany Julien (2019)

Note 17a: 64% of the participants that took part in the interviews strongly disagreed, disagreed or were undecided with the statement that manufacturing-style production system would boost the production in a construction field by 5-10 time. The participants believed the construction culture is dynamic and complex, and applying a manufacturing operating style is bound to fail. In simple context, construction management deals with human, manufacturing operations are more inclined to be automated.

Note 17b: 36% of the participants that took part in the interviews strongly agreed or agreed with the statement which the manufacturing-style production system would boost the production in a construction field by 5-10 time. These participants also understood that applying 100% manufacturing-style operations procedures would not survive during a mega-project. However, these participants were seeking a middle compromise, in line with the continuous improvement philosophy. The researcher enumerates in Table 4.42 various comments made by the participants regarding the productivity in construction.

Table 4. 42
Participants' Remarks: Interview Question 17a-17b

Likert Scale	Participants Comments
1. Strongly Disagree	- 5x to 10x is too high, however there is room from improvement. - Sinking shaft, drilling, blasting, mock clearing, are highly repetitive. - 5x to 10x to high as it equates to 500% to 1000% higher.
2. Disagree	- 5x to 10x mean 500% to 1000% more efficient. This statement is too high. - An improvement of more than 5% to 10% can be achieved in construction management. - 5x to 10x too big of an improvement. - Processes are often in place and good, but unions don't want to adhere it. - 5x to 10x is too high of a number. Modularisation could help production level. - 5x means 500% more efficient. It's impossible. Construction is not that bad. - Manufacturing processes don't work in construction. - Construction has room for improvement but not that much. Stricter control in logistics and procurement can assist better productivity.
3. Undecided	- 5x to 10x too high. Impossible to achieve such improvement. - Technology like RFID shows some opportunities in improve efficiencies but not 5 folds. - Going to a manufacturing standard is sometime hard. It doesn't work that way. - 5x is possible and to 10x is too high.
4. Agree	- Such improvement is possible in manufacturing with lean management. - Lean management in manufacturing offers supply chain improvement. - Reporting set process is possible in construction. For instance, welding and piping. In tank fabrication, there is a high level of mechanical and robotic processes. - For field improvement, the industry need a change in technics. - Modularisation leads to simplification over time. - Stick-built modular is helpful in improving production. - Agree in the productivity statement but the 5x to 10x is too high. - Agree at 45% but depend on the system.
5. Strongly Agree	

Dany Julien (2019)

4.3.5. Knowledge of the SCOR Model

Since the SCOR model is the original basis for the proposed model's framework, the researcher conducted one (1) question regarding the knowledge of the participants toward this model. The researcher illustrates in Table 4.43 the knowledge of the SCOR model amongst the participants. As a result, 71% of the twenty-eight (28) participants never heard of the model before the interviews. On the other hand, 29% of the participants that knew about the SCOR model, their understanding of the model was limited, and their knowledge consisted of previous discussions with the researcher over the three (3) year-period.

Table 4. 43
Participants' Knowledge of the SCOR Model

	Knowledge of SCOR Model		
	Yes	No	Total
Participants	8	20	28
% Participants	29%	71%	100%

Dany Julien (2019)

For the purposed of testing the SCOR Model, its original performance attributes, Level I, II and III metrics were changed in order to reflect the various realities and complexities during the execution of mega-projects. The enriched SCOR Model displayed the same number of performance attributes, although different in meanings, these new attributes are reflections of mega-projects' attributes. The enriched performance attributes belonging to the enriched SCOR Model are shown in Table 4.44. There are also a substantial increased in number of Level I, II and III metrics, most noticeably with Level III (250 KPIs to 366 KPIs). The rest of these enriched Level I, II and III metrics are detailed throughout sections 4.3.7 and 4.3.8 respectively.

Table 4. 44
Enriched SCOR Model

	Performance Attributes	
no.	SCOR Model	Enriched SCOR Model
1	Supply Chain Reliability	Procurement Reliability
2	Supply Chain Responsivene:	Procurement Responsiveness
3	Supply Chain Agility	EPCM Agility
4	Supply Chain Controls	Project Controls
5	Supply Chain Assets Manag	Workers Management
6	Supply Chain Complexity	Project Complexity
7	Supply Chain Maturity	Project Integration

	SCOR Model	Enriched SCOR Model
Performance Attributes (Quantitative)	5	7
Performance Attributes (Qualitative)	2	0
Level I Metrics	10	13
Level II Metrics	27	49
Level III Metrics	250	366

Dany Julien (2019)

4.3.6. Results: Enriched Performance Attributes

The semi-structured interviews measured the supply chain robustness amongst the seven (7) enriched performance attributes. From the original SCOR Model, the supply chain agility, assets management, and supply chain maturity were removed and replaced by performance attributes such as EPCM agility, workers management and project integration. The seven (7) performance attributes were established, they were tested for their supply chain robustness, and calculated as followed:

1. With a Likert scale system, each answer was allocated the following scores:

a. If the participants strongly disagreed in an enriched performance attribute that could be usefully measured during mega-projects, the lowest score of "0" was assigned;

b. If the participants disagreed, a score of "0.25" was given;

c. When the participants were undecided toward an enriched performance attribute, a score of "0.50" was given;

d. When a participant agreed in an enriched performance attribute that could be usefully measured during mega-projects, the score of "0.75" was assigned;

e. If a participant strongly agreed in a statement, the highest score of "1" was attributed.

2. The level of robustness was then calculated by adding the percentage (%) of the number of participants for each Likert score time (x) their respective Likert score. For instance, the robustness of 81.3% from the enriched performance attributes in Table 4.45 was obtained by adding and multiplying the following:

$$\{[0/28]*0 + [2/28]*0.25 + [1/28]*0.50 + [13.5/28]*0.75 + [12/28]*1.0\} = 81.3\%$$

- No participant chose strongly disagreed x "0";
- Two (2) participants out of twenty-eight (28) disagreed x "0.25";
- One (1) participant out of twenty-eight (28) were undecided x "0.50";
- Thirteen (13) participants out of twenty-eight (28) agreed x "0.75";
- Twelve (12) participants out of twenty-eight (28) strongly agreed x "1.0".

Table 4. 45
Calculating Enriched Performance Attributes Scores

Construction Performance & Productivity Model		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
no.	Performance Attributes	1	2	3	4	5	Total	Robustness Level
		0.00	0.25	0.50	0.75	1.00		
1	Procurement Reliability	0	2	1	13	12	28	81.3%
		0%	7%	4%	46%	43%	100%	

Dany Julien (2019)

3. The researcher believes the robustness calculation is reliable, however, also recognizes a limitation. For instance, all the results were calculated and analysed the same way within the semi-structured interviews and survey. The limitation, although, stands on the spread of the results being very closed to each other. Therefore, the researcher recognized the Likert scale should have been scale from 0 to 10, instead of 1 to 5.

All twenty-eight (28) participants scored each enriched performance attribute related to construction project management. The seven (7) enriched performance attributes' robustness were calculated, to which the following results are displayed in Table 4.46.

Table 4. 46
Ratings Enriched Performance Attributes

Construction Performance & Productivity Model		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
no.	Performance Attributes	1	2	3	4	5	Total	Robustness Level
		0.00	0.25	0.50	0.75	1.00		
1	Procurement Reliability	0	2	1	13	12	28	81.3%
		0%	7%	4%	46%	43%	100%	
2	Procurement Responsiveness	0	2	0	13.5	12.5	28	82.6%
		0%	7%	0%	48%	45%	100%	
3	EPCM Agility	0	0	2.5	16	9.5	28	81.3%
		0%	0%	9%	57%	34%	100%	
4	Project Controls	0	1	1	11	15	28	85.7%
		0%	4%	4%	39%	54%	100%	
5	Workers Management	0	1	1	16	10	28	81.3%
		0%	4%	4%	57%	36%	100%	
6	Project Complexity	0	1	2	13.5	11.5	28	81.7%
		0%	4%	7%	48%	41%	100%	
7	Project Integration	0	0	1	15.5	11.5	28	84.4%
		0%	0%	4%	55%	41%	100%	
		0	7	8.5	98.5	82	196	

Dany Julien (2019)

In total, there were 198 responses for this section (performance attributes). In terms of robustness, the enriched performance attribute named Project Controls was the most important one amongst all attributes in construction mega-project. Project Controls scored a level of 85.7% in robustness. The calculation for this performance attribute is demonstrated as followed:

$$[(0 \text{ x } 0.00) + (1 \text{ x } 0.25) + (1 \text{ x } 0.50) + (11 \text{ x } 0.75) + (15 \text{ x } 1.0)] / 28$$
$$= 85.7\%$$

It is important to note that twenty-six (26) of the participants or 91% of them agreed or strongly agreed that Project Controls was an important performance attribute and should be measured during construction mega-projects. On the other side of the spectrum, two (2) participants disagreed or were undecided about the importance of Project controls in a construction project management.

The results in Table 4.46 also demonstrated the top three (3) most important performance attributes in construction mega-projects, were: a) Project Controls (85.7%), b) Project Integration (84.4%), and c) Procurement Responsiveness (82.6%). The bottom four (4) performance attributes were reported as EPCM Agility (81.3%), Workers Management (81.3%), Procurement Reliability (81.3%), and Project Complexity (81.7%).

It is essential to note that the results in Table 4.46 are not the final score for the thesis' artefact (CPPM). In fact, these enriched performance attributes were shown to the participants for the first time during the semi-structured interviews. Some of the robustness scores are expected to change as the semi-structured interviews and survey proceed forward. Nonetheless, the researcher presents in Table 4.47 the comments / remarks made by the participants regarding the seven (7) enriched performance attributes.

Table 4. 47
Participants' Remarks: Enriched Performance Attributes

No	Performance Attributes	Remarks
1	Procurement Reliability	- This attribute is critical for costs.
2	Procurement Responsiveness	- This attribute is critical for costs.
3	EPCM Agility	- This attribute is important for managing change. - Productivity meeting should be once every two weeks has to don't want to cause disruption. - EPCM Agility is most important at the beginning of the project.
4	Project Controls	- Most important metrics. - Important metric to be under control across the entire project. - Project controls may create feuds.
5	Workers (Employee) Management	- This attribute is not important to construction contractors.
6	Project Complexity	- Most input doesn't need to be measured. Off-Site complexity can be detailed. Complexity at site doesn't need to be measured as good planning should take care of it. - This metric is important in large project. More people at a construction site means more congestion.
7	Project Integration	- People don't have an investing interest to close the project. It is hard to get inter-departmental or cross-functional KPIs. - Project integration would be best for a project, but it never happens. There is no will from management. The set-up is too costly and ROI can never be forecasted/ - Project integration is important up front, right at the beginning of planning. But it never happen that way. - Project integration and lesson learnt go hand in hand. However, too often lesson learnt are concluded too late and done too fast during the project. - Project integration must be measured through all phases of project. - For several participants, project integration should start from the beginning. - KPIs should be measured all across each phase.

Dany Julien (2019)

4.3.7. Results: Enriched Level I Metrics

The Enriched SCOR Model proposed initially fourteen (14) Level I metrics. However, a re-adjustment was made after a few semi-structured interviews had been conducted with the participants. Thirteen (13) metrics were eventually kept after following their recommendations. Table 4.48 displays the thirteen (13) enriched Level I metrics that were tested for their robustness during the semi-structured interviews:

Table 4. 48
Enriched Level I Metrics

Enriched SCOR Model

Performance Attributes	Enriched Level I Metrics
Procurement Reliability	Delivery Performance
Procurement Responsiveness	Purchase Order Fulfillment
EPCM Agility	Engineering
	Procurement
	Construction Management
Project Controls	Budget & Planning
	LEM Spends
	Logistics Spends
	Procurement Spends
Workers Management	Workers Information
Project Complexity	Off-Site Complexity
	Job-Site Complexity
Project Integration	Performance Analytics

	SCOR Model	Enriched SCOR Model
Performance Attributes (Quantitative)	5	7
Performance Attributes (Qualitative)	2	0
Level I Metrics	10	13
Level II Metrics	27	49
Level III Metrics	250	366

Dany Julien (2019)

The enriched Level I metrics were presented to the participants during the interviews. The robustness for each metric was calculated as followed:

1. Twenty-eight (28) Participants were evaluated with a Likert scale, regarding the robustness of each enriched Level I metric during construction mega-projects.

a. If the participants strongly disagreed with the metric being useful during construction mega-projects, the lowest score of "0" was assigned;

b. If the participants disagreed with these enriched Level I metrics, a score of "0.25" was given;

c. When the participants were undecided toward the enriched Level I metrics being useful in construction mega-projects, a score of "0.50" was given;

d. When a participant agreed in the Level I metrics being useful in construction mega-projects, the score of "0.75" was assigned;

e. If a participant strongly agreed, the highest score of "1" was attributed.

2. The level of robustness was then calculated by adding the percentage (%) of the participants for each Likert score time (x) their respective Likert score. For instance, the robustness of 80.8% from the enriched Level I metric in Table 4.49 was obtained by adding and multiplying the following:

$$\{[0/28]*0 + [1/28]*0.25 + [1/28]*0.50 + [16.5/28]*0.75 + [9.5/28]*1.0\} = 80.8\%$$

Table 4. 49
Calculating Enriched Level I Metrics

Construction Performance & Productivity Model		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	1 0.00	2 0.25	3 0.50	4 0.75	5 1.00	Total	Robustness Level I
Procurement Reliability								
81.3%	1. Delivery Performance	0 0%	1 4%	1 4%	16.5 59%	9.5 34%	28 100%	80.8%

Dany Julien (2019)

- No participant chose strongly disagreed x "0";
- One (1) participant out of twenty-eight (28) disagreed x "0.25";
- One (1) participant out of twenty-eight (28) were undecided x "0.50";
- Sixteen (16.5) participants out of twenty-eight (28) agreed x "0.75";
- Nine (9.5) participants out of twenty-eight (28) strongly agreed x "1.0".

By order of rankings, the enriched Level I metrics with the highest robustness was the Budget & Planning (a performance attribute belonging to Projects Controls) with a robustness of 88.4%. In second, Construction Management's metrics (a performance attribute belonging to EPCM Agility) had a robustness score of 87.5%. LEM Spends (also from the performance attribute of Project Controls) finished third with a robustness of 87.1%.

Enriched Level I metrics belonging to the performance attributes of Project Controls (Budget & Planning, LEM Spends, Logistics Spends, Procurement Spends) perform the best as a group, with the exception of Procurement Spends which finished in the last tier. Together, Project Controls' Level I metrics finished 1st (88.4%), 3rd (87.1%), 6th (81.7%) and 12th (75.9%).

Enriched Level I metrics belonging to the performance attributes of EPCM Agility (Engineering, Procurement and Construction Management) also performed well as a group. Together, their level of robustness ranked 5th (82.1%) for engineering, 4th (84.8%) for procurement and 2nd (87.5%) for construction management.

The lowest robustness in the enriched Level I metrics belonged to the Procurement Spends (a performance attribute of Project Control) with a score of 75.9%. In second and third last place were Performance Analytics and Workers (Employees) Information finished with 77.2% and 78.6% respectively. Overall, the procurement's enriched Level I metrics did not perform as well as other groups. For instance, Delivery Performance and Purchase Order Fulfilment finished 8th and 9th respectively; and field Procurement (EPCM Agility) was in the 4th position. Finally, Logistics Spends and Procurement Spends from Project Controls finished 6th and 12th overall. The overall results for the enriched Level I metrics are illustrated in Table 4.50, in accordance with the researcher's findings.

Table 4. 50
Ranking Enriched Level I Metrics

No	Level I Metrics	Robustness	Ranking
1	Delivery Performance	80.8%	8
2	Purchase Order Fulfilment	80.4%	9
3	Engineering	82.1%	5
4	Procurement	84.8%	4
5 (6)	Construction Management	87.5%	2
7	Budget & Planning	88.4%	1
8	LEM Spends	87.1%	3
9	Logistics Spends	81.7%	6
10	Procurement Spends	75.9%	12
11	Workers (Employee) Information	78.6%	10
12	Off-Site Complexity	81.3%	7
13	Job Site Complexity	84.8%	4
14	Performance Anaytics	77.2%	11

Dany Julien (2019)

Table 4.51 illustrates in more details, the results of the Level I metrics for all thirteen (13) metrics. Once again, construction and management metrics were presented to the participants as (two) separate metrics, however, the researcher, upon the remarks of several participants, and confirmed by E&C literatures, combined these two (2) metrics into one single enriched Level I metric. The researcher illustrates in Table 4.51, the strength of Project Controls' metrics as well as the EPCM's metrics.

Table 4. 51
Enriched Level I Metrics

Construction Performance & Productivity Model		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	**Level I Metrics**	**1** **0.00**	**2** **0.25**	**3** **0.50**	**4** **0.75**	**5** **1.00**	**Total**	**Robustness Level I**
Procurement Reliability								
81.3%	1. Delivery Performance	0	1	1	16.5	9.5	28	80.8%
		0%	4%	4%	59%	34%	100%	
Procurement Responsiveness								
82.6%	2. Purchase Order Fulfilment	0	1	3	13	11	28	80.4%
		0%	4%	11%	46%	39%	100%	
EPCM Agility								
81.3%	3. Engineering	0	0	0	20	8	28	82.1%
		0%	0%	0%	71%	29%	100%	
	4. Procurement	0	0	0	17	11	28	84.8%
		0%	0%	0%	61%	39%	100%	
	5. Construction	0	0	2	10.5	15.5	28	87.1%
		0%	0%	7%	38%	55%	100%	
	6. Management	0	0	0	13.5	14.5	28	87.9%
		0%	0%	0%	48%	52%	100%	
Project Controls								
85.7%	7. Budget & Planning	0	0	2	9	17	28	88.4%
		0%	0%	7%	32%	61%	100%	
	8. LEM Spends	0	0	1	12.5	14.5	28	87.1%
		0%	0%	4%	45%	52%	100%	
	9. Logistics Spends	0	1	1	15.5	10.5	28	81.7%
		0%	4%	4%	55%	38%	100%	
	10. Procurement Spends	1	1	2	16	8	28	75.9%
		4%	4%	7%	57%	29%	100%	
Workers Management								
81.3%	11. Workers Information	0	2	3.5	11	11.5	28	78.6%
		0%	7%	13%	39%	41%	100%	
Project Complexity								
81.7%	12. Off-Site Complexity	0	1	2	14	11	28	81.3%
		0%	4%	7%	50%	39%	100%	
	13. Job Site Complexity	0	0	1	15	12	28	84.8%
		0%	0%	4%	54%	43%	100%	
	14. Performance Analytics	0	1	3.5	15.5	8	28	77.2%
		0%	4%	13%	55%	29%	100%	
Project Integration		N/A	N/A	N/A	N/A	N/A	N/A	
84.4%								
		1	8	22	199	162	392	

Dany Julien (2019)

4.3.7.1. Enriched Level I Metrics: Participants Remarks

Participants taking part in the interviews provided several comments / remarks along with their robustness scores. The researcher illustrates in Table 4.52, the comments from the participants regarding the enriched Level I metrics.

Table 4. 52
Participants' Remarks: Enriched Level I Metrics

No	Level I Metrics	Remarks
1	Delivery Performance	- Can be improve with interface communication.
2	Purchase Order Fulfilment	- Only measure if it is urgent. - Should be measured especially when Back Order occurs. - Should be measured correctly, not quickly. - Complexity of components make a difference in ordering materials. - Better do it the right way, the first time. You will save total cost. - Timing is essential and critical to field installation. Crews that are down cost a lots of money to the owners and the productivity factors go down automatically. - Late invoicing is hard to measure.
3	Engineering	- Projects are 15% technical and 85% planning, communication, site management.
4	Procurement	
5	Construction Management	- Construction management is as good as the management team. - Communication is key in construction management. - Safety metrics is reported several times as the most important metric in construction. - Metrics should be tracked in construction, however, there are so many changes that data itself may not be meaningful.
6	Budget & Planning	- Estimating, qualitative and quantitative measurement should all be taken into account during projects. - Projects are not only about numbers, they are about human. - Construction manager must understand human factors. Construction managers drive processes and numbers but manage people. - Earned Value versus Burned Value. Burned value is accurate as it is the amount of time clock in and the contractor wish to get pay for. Earned value is an estimate and always questionable by management. Measuring Earned Value has great opportunity for real-time measurement with automation or other reporting system. We must improve field measurement and its Earned Value. - You improve Earned Value measurement and you will improve real-time field productivity accuracy.
7	LEM Spends	- This is very important in Time & Materials contract. - Not as important in Lump sum contract. - This is a very important metrics and must be measured constantly.
8	Logistics Spends	- It's only 10% of the project, hence it should be measured. - It should be measured as it is very important to measure delays against installation dates. Delays are very costly in construction

9	Procurement Spends	- Not required to be measured. It's already measured in pre-construction.
10	Workers (Employee) Information	- No need to be so granular in measurement. Measurement should focus on key results. - This is profile measurement and can measure people that don't perform. - Management don't have time to profile employees. - This is critical to have the best team in the field. - A thirty-year old experience workers don't climb the ladder as fast an apprentice. Team must be homogenous. Analytics will help in forming the best team. - Like in the National Hockey League, coaches will mix their trios to have the best team. Superintendent should mix their team to perform well in completing their packages. Analytics can help. - Performance analytics and workers employees information are hand in hand. - What about the legal aspect. What are you allowed to do with workers information? Do we discriminate when profiling in order to get the best team? Can we fire people based on profiling? - Measuring workers information is micro-managing and not necessary in construction. - This information is critical based on the economics of the project. You must know who is on your staff/crews and you must get the project done. - Corporate staff at site affect your management performance. Too many corporate staff impede your management costs and the possibility of hiring more manager assigned to the field and producing results. Corporate staffs impede field productivity. - Culture in construction offers great improvement, thus measuring management and crew performance offer great opportunity, if management decides to do it. Performance at site must be improved from today's standard.
11	Off-Site Complexity	- This should be part of the Execution Plan. - It's important to plan off-sit complexity, especially for Just-In-Time transport. - This should be done in preliminary planning. - Sometimes, the best price is not the best solutions. Must take off-site complexity seriously. - Should only be analyzed at the beginning of the project. - You need the right mix of complexity. Too complex can be costly with large delays. Not enough complex in mega-projects doesn't exist.
12	Job-Site Complexity	- This should be part of the Execution Plan. - Should be taken for account when congestion occurs. - Should be analyzed at the beginning of the project.
13	Performance Analytics	- Should be measured no more than every two weeks. - Should be measured once a week. - Should be measured weekly or bi-weekly. - This is critical to have the best team in the field. - Should be done daily or weekly. - Performance analytics and workers employees information are hand in hand. - Too much time to invest. Results must be quick. - It should not be ignored. It's the future. - Performance analytics is an important tool to find out productivity factors. - Performance analytics might be good but must have the right benchmarks and you must focus on the project milestone first. - KISS – Keep It Sample and Stupid. Make sure the answers are easy to understand. If the analytics are too complex, you will not get management support, and far less support in the field.

Dany Julien (2019)

4.3.8. Results: Enriched Level II Metrics

The SCOR Model has twenty-seven (27) Level II metrics in its repertoire. When presented to the participants, a further breakdown of forty-nine (49) enriched Level II metrics were tested during the semi-structured interviews. The enriched Level II metrics are presented in the sub-sections 4.3.8.1 to 4.3.8.13.

The level of robustness for each enriched Level II metric was calculated the same way as the enriched Level I metrics' robustness. The calculation made was as followed:

1. Twenty-eight (28) Participants were evaluated using a Likert scale, for finding the robustness for each enriched Level II metric during mega-projects;

   a. If the participants strongly disagreed with the metrics as not being useful during construction mega-projects, the lowest score of "0" was assigned;

   b. If the participants disagreed as not being useful, a score of "0.25" was given;

   c. When the participants were undecided toward the metrics being useful to be measured in construction mega-projects, a score of "0.50" was given;

   d. When a participant agreed in the metrics as being useful in construction mega-projects, the score of "0.75" was assigned;

   e. If a participant strongly agreed as being a very important metric to be measured, the highest score of "1" was attributed.

3. The level of robustness was then calculated by adding the percentage (%) of the participants for each Likert score time (x) their respective Likert score.

4. For instance, the robustness of 76.3% from the enriched Level II metric in Table 4.53 was obtained by adding and multiplying the following:

$$\{[0/28]*0 + [2/28]*0.25 + [2/28]*0.50 + [16.5/28]*0.75 + [7.5/28]*1.0\}$$
$$= 76.3\%$$

Table 4. 53
Calculating Level II Metrics

Level II Metrics	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	Total	Robustness Level II
	1	2	3	4	5		
	0.00	0.25	0.50	0.75	1.00		
1.1. Scheduled Purchase Orders Made by Owner's Request	0	2	2	16.5	7.5	28	76.3%
	0%	7%	7%	59%	27%	100%	

Dany Julien (2019)

- No participant chose strongly disagreed x "0";
- Two (2) participants out of twenty-eight (28) disagreed x "0.25";
- Two (2) participants out of twenty-eight (28) were undecided x "0.50";
- Sixteen (16.5) participants out of twenty-eight (28) agreed x "0.75";
- Seven (7.5) participants out of twenty-eight (28) strongly agreed x "1.0".

The enriched Level II metrics pertaining to the enriched performance attributes of Project Controls (89.5%) had the highest level of robustness. In second and third places respectively, the Level II metrics belonging to Engineering (87.9%) Construction Management (85.0%) dominated the enriched Level II metrics' rankings.

On the other side of the spectrum, several enriched Level II metrics performed below the average target rate of 80%. There were Purchase Order Fulfilment (9th – 79.8%), Delivery Performance (10th – 78.2%), Workers (Employees) Information (11th – 77.5%), Procurement Spends (12th – 75.4%) and Off-site Complexity (13th – 74.8%). Hence, these bottom metrics were the least important Level II metrics for the enriched model. Rankings of the enriched Level II metrics are illustrated in Table 4.54.

Table 4. 54
Ranking Enriched Level II Metrics

	Level I Metrics	Level II	Ranking
Procurement Reliability	Delivery Performance	78.2%	10
Procrrement Responsiveness	Purchase Order Fulfilment	79.2%	9
EPCM Agility	Engineering	87.9%	2
	Procurement	81.6%	7
	Construction Management	85.0%	3
Proejct Controls	Budget & Planning	89.5%	1
	LEM Spends	84.8%	4
	Logistics Spends	82.8%	6
	Procurement Spends	75.4%	12
Workers Management	Workers (Employee) Information	77.5%	11
Project Complexity	Off-Site Complexity	74.8%	13
	Job Site Complexity	83.0%	5
Project Integration	Performance Anaytics	80.6%	8

Dany Julien (2019)

4.3.8.1. Enriched Level II Metrics: Delivery Performance

The Delivery Performance (Level II) metrics pertaining to the enriched performance attribute of Procurement Reliability finished 10th overall in this model with a robustness of 78.2%. It makes this Delivery Performance (Level II) metrics one of the least desirable in the model.

In fact, only the metrics belonging to the “Purchase Orders’ Quality & Accuracy” performed above the 80% target, whereas all the others level II metrics were below that target. The researcher illustrates in Table 4.55, the Delivery Performance (Level II) metrics.

Table 4. 55
Enriched Level II Metrics: Delivery Performance

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Procurement Reliability	1. Delivery Performance	1.1. Scheduled Purchase Orders Made by Owner's Request	0	2	2	16,5	7,5	28	76,3%
			0%	7%	7%	59%	27%	100%	
81,3%	80,8%	1.2. Delivery Performance Against Owner's Requested Date	0	1	3	14,5	9,5		79,0%
			0%	4%	11%	52%	34%	100%	
		1.3. Delivery Performance by Suppliers' Committed Date	0	3	1	15,5	8,5		76,3%
			0%	11%	4%	55%	30%	100%	
		1.4. Perfect Orders' Fulfillment	0	1	3	15,5	8,5		78,1%
			0%	4%	11%	55%	30%	100%	
		1.5 Purchase Orders' Quality & Accuracy	0	1	1	16,5	9,5		80,8%
			0%	4%	4%	59%	34%	100%	
		1.6 Invoices' Accuracy	0	2	2	14	10		78,6%
			0%	7%	7%	50%	36%	100%	
			0	10	12	92,5	53,5	168	78,2%

Dany Julien (2019)

4.3.8.2. Enriched Level II Metrics: Purchase Order Fulfilment

The Purchase Order Fulfilment (Level II) metrics pertaining to the enriched performance attribute of Procurement Responsiveness finished 9th overall in this enriched model with a robustness of 79.2%. It makes this Purchase Order Fulfilment (Level II) metrics also one of the least desirable. The only enriched Level II metrics that performed above the 80% in this category was the “Inquiry Time – Procurement” whereas all others enriched level II metrics were below that target mark. The researcher illustrates in Table 4.56, the robustness for the Purchase Order Fulfilment (Level II) metrics.

Table 4. 56
Enriched Level II Metrics: Purchase Order Fulfilment

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Procurement Responsiveness	2. Purchase Order Fulfilment	2.1 Purchase Order Entry Completed	0	2	0	17	9	28	79,5%
			0%	7%	0%	61%	32%	100%	
82,6%	80,4%	2.2 Invoice Received at Owner	0	1	5	13	9	28	76,8%
			0%	4%	18%	46%	32%	100%	
		2.3 Inquiry Time - Procurement	0	2	2	11	13	28	81,3%
			0%	7%	7%	39%	46%	100%	
			0	5	7	41	31	84	79,2%

Dany Julien (2019)

4.3.8.3. Enriched Level II Metrics: Engineering

The Engineering Level II metrics pertaining to the enriched performance attribute of EPCM Agility finished 2nd overall with a robustness of 87.9%. It makes this Engineering Level II metrics amongst the most desirable in the enriched model. More importantly, all the metrics in this category performed above the 80% target, with the metrics of "Engineering Changes", "Engineering Reworks and Quality-NCR" topping the rankings at 88.4%. The researcher illustrates in Table 4.57 the robustness for the enriched Engineering Level II metrics.

Table 4. 57
Enriched Level II Metrics: Engineering

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
EPCM Agility	3. Engineering	3.1 Engineering Changes	0	0	1	11	16	28	88,4%
			0%	0%	4%	39%	57%	100%	
		3.2 Engineering Drawings	0	0	1	13	14	28	86,6%
			0%	0%	4%	46%	50%	100%	
81,3%	82,1%	3.3 Engineering RFI	0	0	0	14	14	28	87,5%
			0%	0%	0%	50%	50%	100%	
		3.4 Engineering Reworks	0	0	1	11	16	28	88,4%
			0%	0%	4%	39%	57%	100%	
		3.5 Quality - NCR	0	0	2	9	17	28	88,4%
			0%	0%	7%	32%	61%	100%	
			0	0	5	58	77	140	87,9%

Dany Julien (2019)

4.3.8.4. Enriched Level II Metrics: Procurement

The Procurement Level II metrics pertaining to enriched performance attribute of EPCM Agility finished 7th with a robustness of 81.6%. Furthermore, it makes this enriched Level II metrics an average metric for the enriched model. Furthermore, there is only one (1) enriched Level II metric (4.6 Reverse Logistic) which did not perform above the target rate of 80% target in this category. The researcher illustrates in Table 4.58, the robustness for the enriched Procurement (Level II) metrics.

Table 4. 58
Enriched Level II Metrics: Procurement

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
EPCM Agility	4. Procurement	4.1 Material Management	0	0	1	14,5	12,5	28	85,3%
			0%	0%	4%	52%	45%	100%	
		4.2 Transportation Management	0	1	1	15	11	28	82,1%
			0%	4%	4%	54%	39%	100%	
		4.3 Leased Equipment Availability	0	0	1	15	12	28	84,8%
			0%	0%	4%	54%	43%	100%	
81,3%	84,8%	4.4 Inventory Management	0	0	2	11	14	27	83,0%
			0%	0%	7%	39%	50%	96%	
		4.5 Bagging / Expediting at Site	0	1	4	11	12	28	80,4%
			0%	4%	14%	39%	43%	100%	
		4.6 Reverse Logistics	0	1	7	12	8	28	74,1%
			0%	4%	25%	43%	29%	100%	
			0	3	16	78,5	69,5	167	81,6%

Dany Julien (2019)

4.3.8.5. Enriched Level II Metrics: Construction Management

The Construction Management Level II metrics pertaining to the enriched performance attribute of EPCM Agility finished 3rd overall with a robustness of 85.0%. As noted in a previous section, the Level II metrics of Construction and Management has been merged into one metric. In this category, the metric known as "Health, Safety & Environment" obtained the highest score (95.1%) of robustness in this enriched model. This score states the importance of safety concerns in a construction site. In addition, "Site Performance" metrics also performed very well with a robustness of 92%.

On the other hand, the only one metric in the construction management's category that did not perform above the target rate of 80% was the metric of "Information Technology". The researcher illustrates in Table 4.59, the robustness of the enriched Construction Management (Level II) metrics.

Table 4. 59
Enriched Level II Metrics: Construction Management

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
EPCM Agility	5. Construction	5.1 Schedule (FIWP) Development	0	0	2	10,5	15,5	28	87,1%
			0%	0%	7%	38%	55%	100%	
		5.2 Schedule Changes	0	0	2	8,5	17,5	28	88,8%
			0%	0%	7%	30%	63%	100%	
81,3%	87,1%	5.3 Site Performance	0	0	1	7	20	28	92,0%
			0%	0%	4%	25%	71%	100%	
		5.4 Turnover & Commissioning	0	1	0	9,5	17,5	28	88,8%
			0%	4%	0%	34%	63%	100%	
EPCM Agility	6. Management	6.1 Document Control	0	1	1	13,5	12,5	28	83,5%
			0%	4%	4%	48%	45%	100%	
		6.2 Information Technology	1	0	5	12,5	9,5	28	76,3%
			4%	0%	18%	45%	34%	100%	
81,3%	87,9%	6.3 Contract & Labour	0	1	1	11,5	14,5	28	85,3%
			0%	4%	4%	41%	52%	100%	
		6.4 Health, Safety & Environment	0	0	0	5,5	22,5	28	95,1%
			0%	0%	0%	20%	80%	100%	
			1	2	7	43	59	112	85,0%

Dany Julien (2019)

4.3.8.6. Enriched Level II Metrics: Budget & Planning

The Budget & Planning Level II metrics pertaining to the enriched performance attribute of Project Controls finished 1st overall with a robustness of 89.5%. The metric known as "Earned & Burned Indicators" obtained a respective score of 90.6%. The researcher illustrates in Table 4.60, the robustness for the enriched Budget & Planning Management (Level II) metrics.

Table 4. 60
Enriched Level II Metrics: Budget & Planning

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1	2	3	4	5	Total	Robustnes s Level II
			0,00	0,25	0,50	0,75	1,00		
Project Controls	7. Budget & Planning	7.1 Budget	0	1	1	8	18	28	88,4%
85,7%	88,4%		0%	4%	4%	29%	64%	100%	
		7.2 Earned and Burned Indicators	0	0	2	6,5	19,5	28	90,6%
			0%	0%	7%	23%	70%	100%	
			0	1	3	14,5	37,5	56	89,5%

Dany Julien (2019)

4.3.8.7. Enriched Level II Metrics: LEM Spends

The LEM Spends Level II metrics pertaining to the enriched performance attribute of Project Controls finished 4th overall with a robustness of 84.8%. The strongest LEM metrics include "Labour & Management", "Material/Equipment", and "Rework" Spends. These LEM Level II metrics performed well with robustness score in the high eighties. However, only the "IT integration" Spends did not meet the 80% target rate in this category. The researcher illustrates in Table 4.61, the robustness of the enriched LEM Spends (Level II) metrics.

Table 4. 61
Enriched Level II Metrics: LEM Spends

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1	2	3	4	5	Total	Robustnes s Level II
			0,00	0,25	0,50	0,75	1,00		
Project Controls	8. LEM Spends	8.1 Labour & Management Spends	0	0	1	11,5	15,5	28	87,9%
			0%	0%	4%	41%	55%	100%	
		8.2 Material/ Equipment Spends	0	0	1	12,5	14,5	28	87,1%
			0%	0%	4%	45%	52%	100%	
85,7%	87,1%	8.3 Rework Spends	0	1	1	10,5	15,5	28	86,2%
			0%	4%	4%	38%	55%	100%	
		8.4 IT Integration Spends	0	2	1	16,5	8,5	28	78,1%
			0%	7%	4%	59%	30%	100%	
			0	3	4	51	54	112	84,8%

Dany Julien (2019)

4.3.8.8. Enriched Level II Metrics: Logistics Spends

The Logistics Spends Level II metrics pertaining to the enriched performance attribute of Project Controls finished 6th overall with a robustness of 82.8%. All the metrics pertaining to this category obtained scores into the low eighties. The researcher illustrates in Table 4.62, the robustness of the enriched Logistics Spends (Level II) metrics.

Table 4. 62
Enriched Level II Metrics: Logistics Spends

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Project Controls	9. Logistics Spends	9.1 Transportation Spends	0	1	2,5	10,5	14	28	83,5%
			0%	4%	9%	38%	50%	100%	
85,7%	81,7%	9.2 Customs Spends	0	1	2,5	13,5	11	28	80,8%
			0%	4%	9%	48%	39%	100%	
		9.3 Warehouse / Laydown Spends	0	0	3,5	11,5	13	28	83,5%
			0%	0%	13%	41%	46%	100%	
		9.4 Inventory Carrying Costs	0	0	3,5	11,5	13	28	83,5%
			0%	0%	13%	41%	46%	100%	
			0	2	8,5	35,5	38	84	82,8%

Dany Julien (2019)

4.3.8.9. Enriched Level II Metrics: Procurement Spends

The Procurement Spends Level II metrics pertaining to the enriched performance attribute of Project Controls finished 2th overall with a robustness of 75.4%. Furthermore, the average robustness for these enriched Level II metrics did not meet the 80% target benchmark. The researcher illustrates in Table 4.63, the robustness for the enriched Procurement Spends (Level II) metrics.

Table 4. 63
Enriched Level II Metrics: Procurement Spends

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Project Controls	10. Procurement Spends	10.1 Suppliers Spends	0	1	3,5	13,5	10	28	79,0%
			0%	4%	13%	48%	36%	100%	
85,7%	75,9%	10.2 Purchase Order Costs	0	3	4,5	13,5	7	28	71,9%
			0%	11%	16%	48%	25%	100%	
			0	4	8	27	17	56	75,4%

Dany Julien (2019)

4.3.8.10. Enriched Level II Metrics: Workers Information

The Level II metrics for the Workers (Employees) Information, which belong to the enriched performance attribute of Workers Management finished in third last place and 11th overall, with a robustness of 77.5%. None of the enriched Level II metrics met the average robustness of the 80% target benchmark. The researcher illustrates in Table 4.64, the robustness for the enriched Workers Information (Level II) metrics.

Table 4. 64
Enriched Level II Metrics: Workers Information

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Workers Management	11. Workers Information	11.1 Labour Force's Information	0,5	2,5	1,5	12,5	11	28	77,7%
			2%	9%	5%	45%	39%	100%	
81,3%	78,6%	11.2 Management Information	0,5	2,5	2	12	11	28	77,2%
			2%	9%	7%	43%	39%	100%	
			1	5	3,5	24,5	22	56	77,5%

Dany Julien (2019)

4.3.8.11. Enriched Level II Metrics: Off-Site Complexity

The Off-Site Complexity Level II metrics pertaining to the enriched performance attribute of Project Complexity finished in last place or 13th overall with a robustness of 74.8%. The average robustness for these enriched Level II metrics did not meet the

80% target benchmark. Furthermore, participants' remarks also confirmed these metrics appeared to be only important during the pre-construction phase, and once the project is underway, the construction stakeholders should not place much importance to them. The researcher illustrates in Table 4.65, the robustness of these enriched Off-Site Complexity (Level II) metrics.

Table 4. 65
Enriched Level II Metrics: Off-Site Complexity

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Project Complexity	12. Off-Site Complexity	12.1 Manufacturing Complexity		1	4	16	7	28	75,9%
			0%	4%	14%	57%	25%	100%	
		12.2 Distribution Complexity		1	4	15	8	28	76,8%
			0%	4%	14%	54%	29%	100%	
81,7%	81,3%	12.3 Supplier Base Complexity		1	5	14	8	28	75,9%
			0%	4%	18%	50%	29%	100%	
		12.4 IT Base Complexity	1		8	13	6	28	70,5%
			4%	0%	29%	46%	21%	100%	
			1	3	21	58	29	112	74,8%

Dany Julien (2019)

4.3.8.12. Enriched Level II Metrics: Job-Site Complexity

The Job-Site Complexity Level II metrics pertaining to the enriched performance attribute of Project Complexity rated much better than the Off-Site metrics by finishing 5th overall for this enriched model with an average robustness of 83.0%. Participants in the interviews noted the importance of congestion and its effect over work efficiencies. The researcher illustrates in Table 4.66 the robustness for the enriched Job-Site Complexity Level II metrics.

Table 4. 66
Enriched Level II Metrics: Job-Site Complexity

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Project Complexity	13. Job Site Complexity	13.1 Contractor Base Complexity			1	16	11	28	83,9%
			0%	0%	4%	57%	39%	100%	
81,7%	84,8%	13.2 Management Team / Owner Represetatives			2	16	10	28	82,1%
			0%	0%	7%	57%	36%	100%	
			0	0	3	32	21	56	83,0%

Dany Julien (2019)

4.3.8.13. Enriched Level II Metrics: Performance Analytics

The Performance Analytics (Level II) metrics pertaining to the enriched performance attribute of Project Integration finishing 8th overall with a robustness of 80.6%. Performance analytics, as stated in the participants' remarks received mixed reviews on either its importance of being measured or not. The researcher illustrates in Table 4.67, the robustness for the Performance Analytics (Level II) metrics.

Table 4. 67
Level II Metrics: Performance Analytics

Construction Performance & Productivity Model			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree		
Performance Attributes	Level I Metrics	Level II Metrics	1 0,00	2 0,25	3 0,50	4 0,75	5 1,00	Total	Robustness Level II
Project Integration	14. Performance Analytics	14.1 Level II Metrics		0,5	4,5	12	11	28	79,9%
			0%	2%	16%	43%	39%	100%	
84,4%	77,2%	14.2 Performance Analytics		0,5	4	11,5	12	28	81,3%
			0%	2%	14%	41%	43%	100%	
			0	1	8,5	23,5	23	56	80,6%

Dany Julien (2019)

4.3.8.14. Enriched Level II Metrics: Participants Remarks

Participants taking part in the interviews provided several comments on the importance (or not) of the enriched Level II metrics. The researcher enumerated in Table 4.68 the comments from the participants regarding these enriched Level II metrics.

Table 4. 68
Participants' Remarks: Enriched Level II Metrics

No	Level II Metrics	Remarks
1.1	Schedule Purchase Orders Made by Owner's Request	- This metric should be merged with 1.2. - This is the same as 1.2. - Useful metrics. Owners make often dump demand out of line, which adds up costs. - This metric all affect overall forecast.
1.2	Delivery Performance Against Owner's Requested Date	- This metric should be merged with 1.1. - This is the same as 1.1. - This metric all affect overall forecast.
1.3	Delivery Performance by Suppliers' committed Date	- Metrics useful to check suppliers' lies. - This metric all affect overall forecast.
1.4	Perfect Orders' Fulfilment	- This metric all affect overall forecast.
1.5	Purchase Orders' Quality & Accuracy	- This metric all affect overall forecast.
1.6	Invoices' Accuracy	- These metrics all affect overall forecast.
2.1	Purchase Order Entry Completed	- This metric makes no sense if it is owners' equipment. - These metrics all affect overall forecast.
2.2	Invoice Received at Owner	- Useful for evaluation in the past (lesson learned). During construction, this metric is not useful. We don't have staffs at site to do this kind of works. Leave it for corporate procurement. - This metric makes no sense if it is owner equipment. - These metrics all affect overall forecast.
2.3	Inquiry Time – Procurement	- This metric makes no sense if it is owner equipment. - These metrics all affect overall forecast.
3.1	Engineering Changes	- This metric will affect bottom-line.
3.2	Engineering Drawings	- Most important metrics for IFC – Issue for construction. - This metric will affect bottom-line.
3.3	Engineering RFI	- This metric will affect bottom-line.
3.4	Engineering Reworks	- This metric should be merged with 3.5. - This is the same metric as 3.5. - This metric will affect bottom-line.
3.5	Quality – NCR	- This metric should be merged with 3.4. - This is the same metric as 3.4. - This metric will affect bottom-line.
4.1	Material Management	- This metric will affect Performance and high costs.
4.2	Transportation Management	- This metric will affect Performance and high costs.
4.3	Leased Equipment Availability	- It is important to monitor leased equipment used especially in Time & Materials contracts. Lots of grease and abuse in having too many equipment, which project owners end up paying for nothing. For instance, having welding (six-pack) machine on every floors instead of organizing a logistics for them. For instance, they are more welding machine than welders at site. - Very important to monitor. Lots of abuse by contractors.

		- Small monetary amount in a multi-million dollar contract but it adds up over time. - Watch contractors. Leasing equipment is gravy money for contractors. - The more trades at site, the more leased equipment at site, and the more waste of money with equipment sitting idle. - This metric will affect Performance and high costs.
4.4	Inventory Management	- This metric will affect Performance and high costs.
4.5	Bagging/Expediting at Site	- This metric will affect Performance and high costs.
4.6	Reverse Logistics	- This metric is not important in planning or at the beginning of the project. - This metric is more important at the end of the project. - It a necessity but not a priority. - This is after the fact activities. Not as important to track. - This metric will affect Performance and high costs.
5.1	Schedule (FIWP) Development	
5.2	Schedule Changes	- This is an important metric. It impacts on the schedule completion.
5.3	Site Performance	
5.4	Turnover & Commissioning	- This metric is not important in planning or at the beginning of the project.
6.1	Document Control	- The activity is important, but should not be measured. - Need proper office management. Important activities.
6.2	IT	
6.3	Contract & Labor	- This metric should be Contracts & Disputes. This metric is important to avoid loop holes which contractors are good at detecting. - Contractors are experienced in field disputes. - When pressure to finish by certain contractual date, it increase labour and costs.
6.4	Health, Safety & Environment	- Most important metrics. - Very important metrics. - This is worth 5.5 over 5! Most important metrics. - Most important metrics to track.
7.1	Budget	- There are so many variable affecting budget. It is hard to measure. - Budget metrics are affected by the types of contract. For instance, Time & Materials or Lump Sum contracts. - This metric is important to measure Actual versu Planned.
7.2	Earned & Burned Indicators	- This is the job of Quality Surveyors. - Important metric for audit performance.

8.1	Labour & Management Spends	
8.2	Material / Equipment Spends	
8.3	Reworks Spends	- Not an important metrics until it becomes an issue.
8.4	IT Integration Spends	- There is seldom a budget allocated for IT in project. - RFID (tracking materials) and Project Wise (project management software) are common in project.
9.1	Transportation Spends	
9.2	Customs Spends	
9.3	Warehouse / Laydown Spends	- This is not construction matters.
9.4	Inventory Carrying Costs	- This is important in manufacturing, not construction. Construction is more concerned with warranty and preservation. - Having equipment at site too long or lack of preservation can cost you the warranty. - Don't worry about this metrics, this is HQ business, not construction. - Warranty, damage and preservation more important. - Do we have to measure ICC for compressor and bolts and washer too? You can measure the ICC case by case. - Threat of shutdown, loss revenue at site is more important than knowing your ICC. - This is a project control metrics. If planning and scheduling control are in place, the ICC has no importance.
10.1	Suppliers Spends	- These are corporate metrics. As long as your materials are at site, you don't care about how much you spends per suppliers.
10.2	Purchase Order Costs	- Too micro-management. Not necessary for site metrics Good for corporate at HQ. - This is a repetitive metrics. It should be removed. - This is micro-information. Not required to be measured in construction. - In order to cut down the price of phase, we have to stop the shopping around and slow down installation.
11.1	Labour Force's information	- This looks like profiling. It can be legally challenged. - Contractors should be able to do their own sourcing of employees, not by profiling them at site. - Construction don't do enough of it. - Construction don't use information at their own advantage. - Profiling - what about legislation. - Asking about age, sex, union name, is illegal except for safety and medical procedures. For instance, washroom set-up at site. - Just need trade qualifications, not age, sex, etc. to meet legislation requirement. For instance, course, experience and training. - Sex, age, etc. are irrelevant metrics.

11.2	Management Information	- Construction don't do enough of it. - Profiling – what about legislation. - Asking about age, sex, union name, is illegal except for safety and medical procedures. For instance, washroom set-up at site. - Just need trade qualifications, not age, sex, etc. to meet legislation requirement. For instance, course, experience and training.
12.1	Manufacturing Complexity	- We should not worry about this metric in construction. - This metric should be done before the execution.
12.2	Distribution Complexity	- We should not worry about this metric in construction. - This metric should be done before the execution.
12.3	Suppler Base Complexity	- We should not worry about this metric in construction. - This metric should be done before the execution.
12.4	IT Base Complexity	- We should not worry about this metric in construction. - This metric should be done before the execution.
13.1	Contractor Base Complexity	
13.2	Management Team / Owner Representatives	- Need the right balance of management and labour. - Corporate at site. Too many cooks in the kitchen. They take the place of CMT that could be use more effectively.
14.1	Level II Metrics	- This metric is dependent on the client if they want to that much details. - Yes it should be done. - You have to be a believer in analytics. - Performance is usually measure qualitatively. - These metrics should be done every day. But you don't need profiling details. - Very important metrics. - These metrics should be on a monthly report. - Good benchmarking.
14.2	Performance Analytics	- This metric is dependent on the client if they want to that much details. - Yes it should be done. - These metrics should be done every day. But you don't need profiling details. - Very important metrics. - This metrics should be on a monthly report. - Good benchmarking. - This is important for direct productivity measurement. - Recommend Indirect Productivity – set for warehouse to field installation.

Dany Julien (2019)

4.3.9. Results: Enriched Level III Metrics

The SCOR Model presents 250 Level III metrics whereas, once the model was enriched by the researcher with mega-projects KPIs, the enriched SCOR Model ended up with 366 KPI. Then, due to the large number of enriched Level III metrics, the researcher felts that, first, the participants wouldn't have the time to rank each one of them, thus a fear of losing their attention during the semi-structured interviews. Secondly, the researcher felt that testing all enriched Level III metrics would have forced the participants to bulk-ranked the metrics' robustness just to expedite their personal time.

Since the researcher understood that participants were senior managers and could not spent hours in answering questions, the researcher decided not to interview the participants regarding the selection of the most important enriched Level III metrics. Instead, the researcher calculated the Level III robustness based on previous scores obtained from the ranking of its enriched performance attributes, Level I metrics and Level II metrics. The researcher recognizes the limitations of not having tested the Level III metrics at this stage of the research. However, the objectives of the semi-structured interviews were to sort out the most evident enriched Level III metrics. This sorting out or segmentation was accomplished through a four-way processes.

The first process in segmenting the most important enriched performance attributes and Level I, II and III metrics at the end of the semi-structured interviews was to calculate the robustness of the enriched Level III metrics as shown below in Table 4.69.

(% Performance Attribute) x (% Level I) x (% Level II) = Level III Robustness

81.3% x 80.8% x 78.6% = 80.2%

Table 4. 69
Delivery Performance Level III Metrics

Construction Performance & Productivity Model					
1		Performance Attribute: Procurement Reliability	Level II	Level III	
	Level 1	1. Delivery Performance	78,2%	Robustness	# of metrics
		1.1 Delivery Performance Against Owner's / Contractors Requested Date	77,7%	79,9%	16
81,3%		1.2 Delivery Performance by Suppliers' Committed Date	76,3%	79,5%	5
	80,8%	1.3 Perfect Orders' Fulfillment Arriving at Construction Site	78,1%	80,1%	2
		1.4 Purchase Orders' Quality & Accuracy	80,8%	81,0%	7
		1.5 Invoices' Accuracy	78,6%	80,2%	10

Dany Julien (2019)

The second process was to categorize the enriched Level III metrics into five (5) subcategories of importance. In terms of Level III's robustness ranking, the researcher subdivided the Level III (366 KPIs) metrics with their respected Level II (49 metrics) into five tiers:

a) 1st tier were the enriched Level II/II metrics that achieved the ranking of 1 to 10;
b) 2nd tier were the enriched Level II/II metrics with the ranking between 11 and 20;
c) 3rd tier were the enriched Level II/II metrics with the ranking between 21 to 30;
d) 4th tier were the enriched Level II/II metrics with the ranking between 31 and 38, and lastly;
e) the 5th tier were the enriched Level II/II metrics with the ranking score between 39 and 49.

The third process was to remove the last set of Level II/III metrics (5th tier) from the enriched SCOR Model. Finally, the last process in segmenting the most important enriched performance attributes and Level I, II, and III metrics at the end of the semi-structured interviews was to test the top four (1st to 4th) tiers of Level III metrics, through an electronic a survey. The researcher thinks the validation of Level III metrics through a survey will be much better than having gone through a second lengthy interview process. The survey's results are discussed in section 4.4 of this chapter.

4.3.9.1. Enriched Level III Metrics: 1st and 2nd Tier

The 1st tier (1 to 10) and 2nd tier (11 to19) for Level III metrics are once again dominated by enriched performance attributes belonging to Project Controls and EPCM Agility, which both had five (5) metrics each. The top 10 or 1st tier Level III metrics comprises the following enrichment:

- Two (2) performance attributes pertinent to mega-projects;
- Three (3) Level I metrics pertinent to mega-projects;
- Ten (10) Level II metrics pertinent to mega-projects; and
- Eighty-six (86) Level III metrics pertinent to mega-projects.

The 2nd tier Level III metrics demonstrated that nine (9) of the metrics belonged to Project Controls' and eleven (11) of them were pertaining to the category of EPCM Agility. The 2nd tiers Level III metrics comprises the following enrichment:

- Two (2) performance attributes pertinent to mega-projects;
- Five (5) Level I metrics pertinent to mega-projects;
- Twenty (20) Level II metrics pertinent to mega-projects; and
- 92 Level III metrics pertinent to mega-projects.

The researcher's findings are illustrated in Table 4.70 and represent the 1st tier and 2nd tier for the enriched Level III metrics rankings.

Table 4. 70
Enriched Level III Metrics: 1st and 2nd Tier

Enriched SCOR Model - 1st Tier						Category Ranking
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	5. Construction Management	85,0%	Robustness	# of metrics	
81,3%	87,1%	5.1 Schedule (FIWP) Development	87,1%	85,7%	12	8
		5.2 Schedule Changes	88,8%	86,8%	5	5
		5.3 Construction Site Performance	92,0%	85,7%	23	9
81,3%	87,9%	5.7 Contract / Labour Issues & Solving	85,3%	84,8%	8	10
		5.8 Health, Safety & Environment	95,1%	88,1%	17	2
4	Enriched Performance Attribute: Project Control		Level II	Level III		
	Level 1	6. Budget & Planning	89,5%	Robustness	# of metrics	
85,7%	88,4%	6.1 Budget (Acutal vs. EAC)	88,4%	87,5%	5	3
		6.2 Earned and Burned Indicators	90,6%	88,2%	3	1
4	Enriched Performance Attribute: Project Control		Level II	Level III		
	Level 1	7. LEM Spends	84,8%	Robustness	# of metrics	
85,7%	87,1%	7.1 Labour (+ Management) Spends	87,9%	86,9%	4	4
		7.2 Equipment + Materials Spends	87,1%	86,6%	5	6
		7.3 Rework Spends	86,2%	86,3%	4	7

Enriched SCOR Model - 2nd Tier						Category Ranking
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	3. Engineering	87,9%	Robustness	# of metrics	
81,3%	82,1%	3.1 Engineering Changes Orders	88,4%	83,9%	6	13
		3.3 Engineering RFI	87,5%	83,6%	9	20
		3.4 Engineering Reworks & NCR	88,4%	83,9%	28	11
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	4. Procurement	81,6%	Robustness	# of metrics	
81,3%	84,8%	4.1 Material Management at Site	85,3%	83,8%	19	15
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	5. Construction Management	85,0%	Robustness	# of metrics	
81,3%	87,1%	5.4 Turnover & Commissioning	88,8%	83,9%	9	14
81,3%	87,9%	5.5 Document Control	83,5%	84,2%	2	11
4	Enriched Performance Attribute: Project Control		Level II	Level III		
	Level 1	7. LEM Spends	84,8%	Robustness	# of metrics	
85,7%	87,1%	7.4 IT Integration Spends	78,1%	83,6%	4	19
4	Enriched Performance Attribute: Project Control		Level II	Level III		
	Level 1	8. Logistics Spends	82,8%	Robustness	# of metrics	
85,7%	81,7%	8.1 Transportation Spends	83,5%	83,6%	6	18
		8.3 Warehouse / Laydown Spends	83,5%	83,6%	2	16
		8.4 Inventory Carrying Costs Spends	83,5%	83,6%	7	17

Dany Julien (2019)

4.3.9.2. Enriched Level III Metrics: 3rd and 4th Tier

The 3rd tier (21-30) and the 4th tier (31-38) of robustness for the enriched Level III metrics are noticeable by a mixture of metrics belonging to several enriched performance attributes. Beginning with the 3rd tier's Level III metrics, the performance attribute of Project Complexity, Procurement Reliability and Responsiveness have started to show some level of robustness. Furthermore, it should be pointed out that only the Job-Site Complexity's metric within the performance attribute of the Project Complexity is represented in this 3rd tier Level III metrics.

The performance attribute belonging to Procurement Reliability and Responsiveness has only one Level III metrics in the top 30 Level III metrics. These scores demonstrate once again, the low priority for supply chain metrics in mega-projects; and an evidence that construction mega-projects are led by a project control driven-culture, and an engineering & construction driven-culture. The performance attribute belonging to Procurement Reliability and Responsiveness finally showed some robustness at the beginning of the 4th tier (position of 31 to 38).

The reader must note that Level III metric 1.3 "Perfect Orders' Fulfilment Arriving at Construction Site" in the 4th tier was removed from the enriched SCOR Model due to several participants' remarks pointing out the duplication with metric 1.4 (Purchase Orders' Quality & Accuracy). The researcher's findings for 3rd and 4th tier Level III ranking are illustrated in Table 4.71. The top 30 or 3rd tiers Level III metrics comprises the position 21 to 30 and have the following enrichment:

- Four (4) performance attributes pertinent to mega-projects;
- Six (6) Level I metrics pertinent to mega-projects;
- Ten (10) Level II metrics pertinent to mega-projects; and
- 99 Level III metrics pertinent to mega-projects.

The top 4th tiers Level III metrics comprises the position 31 to 38 and have the following enrichment:

- Five (5) performance attributes pertinent to mega-projects;
- Five (5) Level I metrics pertinent to mega-projects;
- Nine (9) Level II metrics pertinent to mega-projects; and
- Thirty-nine (39) Level III metrics pertinent to mega-projects.

Table 4. 71
Enriched Level III Metrics: 3rd Tier and 4th Tier

Enriched SCOR Model - 3rd Tier						Category Ranking
2	Enriched Performance Attribute: Procurement Responsiveness		Level II	Level III		
82,6%	Level 1	2. Purchase Order Fulfilment	79,2%	Robustness	# of metrics	
	80,4%	2.3 Time to Respond to Procurement Inquiries	81,3%	81,4%	2	30
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
81,3%	Level 1	3. Engineering	87,9%	Robustness	# of metrics	
	82,1%	3.2 Engineering Drawing Changes	86,6%	83,3%	4	23
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
81,3%	Level 1	4. Procurement	81,6%	Robustness	# of metrics	
	84,8%	4.2 Transportation Management	82,1%	82,7%	6	27
		4.3 Leased Equipment Used at Site	84,8%	83,6%	3	21
		4.4 Inventory Management	83,0%	83,0%	5	24
		4.5 Bagging / Free Issue to Contractos / Expediting at Site	80,4%	82,1%	4	28
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	5. Construction Management	85,0%	Robustness	# of metrics	
81,3%	87,9%	5.6 IT Integration Issues & Solving	76,3%	81,8%	4	29
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	8. Logistics Spends	82,8%	Robustness	# of metrics	
	81,7%	8.2 Customs Spends	80,8%	82,7%	2	26
6	Enriched Performance Attribute: Project Complexity		Level II	Level III		
	Level 1	12. Job Site Complexity	83,0%	Robustness	# of metrics	
81,7%	84,8%	12.1 Contractor Base Complexity	83,9%	83,5%	47	22
		12.2 Management Team / Owner Represetatives	82,1%	82,9%	13	25

Enriched SCOR Model - 4th Tier						Category Ranking
1	Enriched Performance Attribute: Procurement Reliability		Level II	Level III		
	Level 1	1. Delivery Performance	78,2%	Robustness	# of metrics	
81,3%		1.3 Perfect Orders' Fulfillment Arriving at Construction Site	78,1%	80,1%	2	37
	80,8%	1.4 Purchase Orders' Quality & Accuracy	80,8%	81,0%	7	32
		1.5 Invoices' Accuracy	78,6%	80,2%	10	36
2	Enriched Performance Attribute: Procurement Responsiveness		Level II	Level III		
82,6%	Level 1	2. Purchase Order Fulfilment	79,2%	Robustness	# of metrics	
	80,4%	2.1 Time to Complete Purchase Order Entries	79,5%	80,8%	5	33
		2.3 Time to Respond to Procurement Inquiries	81,3%	81,4%	2	30
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
81,3%	Level 1	4. Procurement	81,6%	Robustness	# of metrics	
	84,8%	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	74,1%	80,1%	3	38
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	9. Procurement Spends	75,4%	Robustness	# of metrics	
	75,9%	9.1 Suppliers Spends	79,0%	80,2%	6	35
7	Enriched Performance Attribute: Project Integration		Level II	Robustness	# of metrics	
84,4%	Level 1	13. Performance Anaytics	80,6%	N/A	N/A	
	77,2%	13.2 Level III Metrics	81,3%	81,0%	1	31
		13.3 Performance Analytics	81,3%	80,4%	3	34

Dany Julien (2019)

4.3.9.3. *Enriched Level III Metrics: 5th Tier*

Finally, the Level III metrics that scored the lowest robustness throughout this enriched SCOR Model felt into the 5th tier (position 39 to 49). Two noticeable facts about these rejected metrics were their scores below the 80% benchmark and the metrics belonging to the "Off-Site Complexity" were all ranked in the last tier. Hence, once the semi-structured interviews completed and analysed, the researcher removed from the enriched SCOR Model a total sixty (61) Level III metrics from the initial 366 metrics. The rejected Level III metrics pertaining to the enriched SCOR Model are illustrated in Table 4.72.

Table 4. 72
Enriched Level III Metrics: 5th Tier

Enriched SCOR Model - 5th Tier						Category Ranking
1	Enriched Performance Attribute: Procurement Reliability		Level II	Level III		
81,3%	Level 1	1. Delivery Performance	78,2%	Robustness	# of metrics	
	80,8%	1.1 Delivery Performance Against Owner's / Contractors Requested Date	77,7%	79,9%	16	39
		1.2 Delivery Performance by Suppliers' Committed Date	76,3%	79,5%	5	45
2	Enriched Performance Attribute: Procurement Responsiveness		Level II	Level III		
82,6%	Level 1	2. Purchase Order Fulfilment	79,2%	Robustness	# of metrics	
	80,4%	2.2 Time to Receive Invoices from Suppliers/Contractors to Owners	76,8%	79,9%	4	41
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	9. Procurement Spends	75,4%	Robustness	# of metrics	
	75,9%	9.2 Costs to Execute Purchase Orders	71,9%	77,8%	3	48
5	Enriched Performance Attribute: Workers (Employee) Management		Level II	Level III		
81,3%	Level 1	10. Workers (Employee) Information	77,5%	Robustness	# of metrics	
	78,6%	10.1 Labour Force's Personal Information	77,7%	79,2%	7	46
		10.2 Management Staff's Personal Information	77,2%	79,0%	5	47
6	Enriched Performance Attribute: Project Complexity		Level II	Level III		
81,7%	Level 1	11. Off-Site Complexity	74,8%	Robustness	# of metrics	
	81,3%	11.1 Manufacturing Complexity	75,9%	79,6%	2	43
		11.2 Distribution Complexity	76,8%	79,9%	9	42
		11.3 Supplier Base Complexity	75,9%	79,6%	3	44
		11.4 IT Base Complexity	70,5%	77,8%	5	49
7	Enriched Performance Attribute: Project Integration		Level II	Robustness	# of metrics	
84,4%	Level 1	13. Performance Anaytics	80,6%	N/A	N/A	
	77,2%	13.1 Level II Metrics	79,9%	80,5%	1	40

Dany Julien (2019)

4.3.9.4. *Enriched Level III Metrics: Performance Attributes*

Following the results of the semi-structured interviews, this research finds that both enriched Level III metrics belonging to the performance attributes of Project Controls and EPCM Agility were the most important metrics of this enriched SCOR Model, followed by Procurement Reliability and Responsiveness. The enriched Level III metrics for the performance attributes including Project Complexity, Project Integration and Workers' Management were the lesser important ones.

4.3.9.5. Enriched Level III: Procurement Reliability and Responsiveness

The enriched Level III metrics which belong to the performance attributes of Procurement Reliability and Responsiveness have not performed well in terms of overall robustness for this enriched model. Excepting metrics 2.3 which finished in the 3rd tier, all of the other Level III metrics in Procurement Reliability and Responsiveness were found in the 4th or 5th tier of the model.

There is a total of fifty-one (51) Level III metrics in the attributes of Procurement Reliability & Responsiveness. Three (3) of them (1.1, 1.2, and 2.2) did score below the 80% target level of robustness and will be not be introduced during the final survey. The researcher's findings are illustrated in Table 4.73, with the ranking of Level III metrics in the Procurement Reliability & Responsiveness.

Table 4. 73
Enriched Level III Metrics: Procurement Reliability & Responsiveness

Perf. Attribute: Procurement Reliability & Responsiveness		Robustness	Overall Ranking	Tiers 1-5	Category Ranking
TOP 8	**Enriched Level III Metrics**				
1	2.3 Time to Respond to Procurement Inquiries	**81,4%**	30	3	1
2	1.4 Purchase Orders' Quality & Accuracy	**81,0%**	31	4	2
3	2.1 Time to Complete Purchase Order Entries	**80,8%**	33	4	3
4	1.5 Invoices' Accuracy	**80,2%**	36	4	4
5	1.3 Perfect Orders' Fulfillment Arriving at Construction Site	**80,1%**	37	4	5
6	1.1 Delivery Performance Against Owner's / Contractors' Requested Date	**79,9%**	39	5	6
7	2.2 Time to Receive Invoices from Suppliers/Contractors to Owners	**79,9%**	41	5	6
8	1.2 Delivery Performance by Suppliers' Committed Date	**79,5%**	45	5	7

Enriched SCOR Model						Category Ranking
1		**Enriched Performance Attribute: Procurement Reliability**	**Level II**	**Level III**		
	Level 1	**1. Delivery Performance**	**78,2%**	**Robustness**	**# of metrics**	
81,3%	**80,8%**	1.1 Delivery Performance Against Owner's / Contractors Requested Date	**77,7%**	**79,9%**	16	39
		1.2 Delivery Performance by Suppliers' Committed Date	**76,3%**	**79,5%**	5	45
		1.3 Perfect Orders' Fulfillment Arriving at Construction Site	**78,1%**	**80,1%**	2	37
		1.4 Purchase Orders' Quality & Accuracy	**80,8%**	**81,0%**	7	32
		1.5 Invoices' Accuracy	**78,6%**	**80,2%**	10	36
2		**Enriched Performance Attribute: Procurement Responsiveness**	**Level II**	**Level III**		
	Level 1	**2. Purchase Order Fulfilment**	**79,2%**	**Robustness**	**# of metrics**	
82,6%	**80,4%**	2.1 Time to Complete Purchase Order Entries	**79,5%**	**80,8%**	5	33
		2.2 Time to Receive Invoices from Suppliers/Contractors to Owners	**76,8%**	**79,9%**	4	41
		2.3 Time to Respond to Procurement Inquiries	**81,3%**	**81,4%**	2	30

Dany Julien (2019)

4.3.9.6. Enriched Level III Metrics: EPCM Agility

Level III metrics which belong to the performance attributes of EPCM Agility have performed well in terms of overall robustness in this enriched model, as they felt under the 1st, 2nd and 3rd tier, except for a procurement metric (4.6 – Reverse Logistics) that was locked down in the 4th tier. There is a total of 167 enriched Level III metrics in the performance attribute of EPCM Agility. All of them will be introduced to the participants of the final survey. The researcher's findings are illustrated in Table 4.74.

Table 4. 74
Enriched Level III Metrics: EPCM Agility

Perf. Attribute: EPCM Agility		Robustness	Overall Ranking	Tiers 1-5	Category Ranking
TOP 18	Enriched Level III Metrics				
1	5.8 Health, Safety & Environment	88,1%	2	1	1
2	5.2 Schedule Changes	86,8%	5	1	2
3	5.1 Schedule (FIWP) Development	85,7%	8	1	3
4	5.3 Construction Site Performance	85,7%	9	1	3
5	5.7 Contract / Labour Issues & Solving	84,8%	10	1	4
6	5.5 Document Control	84,2%	11	2	5
7	3.4 Engineering Reworks & NCR	83,9%	12	2	6
8	3.1 Engineering Changes Orders	83,9%	13	2	6
9	5.4 Turnover & Commissioning	83,9%	14	2	6
10	4.1 Material Management at Site	83,8%	15	2	7
11	3.3 Engineering RFI	83,6%	20	2	9
12	4.3 Leased Equipment Used at Site	83,6%	21	3	9
13	3.2 Engineering Drawing Changes	83,3%	23	3	10
14	4.4 Inventory Management	83,0%	24	3	11
15	4.2 Transportation Management	82,7%	27	3	8
16	4.5 Bagging / Free Issue to Contractos / Expediting at Site	82,1%	28	3	12
17	5.6 IT Integration Issues & Solving	81,8%	29	3	13
18	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	80,1%	38	4	14

Enriched SCOR Model						Category Ranking
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	3. Engineering	87,9%	Robustness	# of metrics	
81,3%	82,1%	3.1 Engineering Changes Orders	88,4%	83,9%	6	13
		3.2 Engineering Drawing Changes	86,6%	83,3%	4	23
		3.3 Engineering RFI	87,5%	83,6%	9	20
		3.4 Engineering Reworks & NCR	88,4%	83,9%	28	11
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	4. Procurement	81,6%	Robustness	# of metrics	
81,3%	84,8%	4.1 Material Management at Site	85,3%	83,8%	19	15
		4.2 Transportation Management	82,1%	82,7%	6	27
		4.3 Leased Equipment Used at Site	84,8%	83,6%	3	21
		4.4 Inventory Management	83,0%	83,0%	5	24
		4.5 Bagging / Free Issue to Contractos / Expediting at Site	80,4%	82,1%	4	28
		4.6 Reverse Logistics (Auction, Surplus, Obsolete)	74,1%	80,1%	3	38
3	Enriched Performance Attribute: EPCM Agility		Level II	Level III		
	Level 1	5. Construction Management	85,0%	Robustness	# of metrics	
81,3%	87,1%	5.1 Schedule (FIWP) Development	87,1%	85,7%	12	8
		5.2 Schedule Changes	88,8%	86,8%	5	5
		5.3 Construction Site Performance	92,0%	85,7%	23	9
		5.4 Turnover & Commissioning	88,8%	83,9%	9	14
		5.5 Document Control	83,5%	84,2%	2	11
81,3%	87,9%	5.6 IT Integration Issues & Solving	76,3%	81,8%	4	29
		5.7 Contract / Labour Issues & Solving	85,3%	84,8%	8	10
		5.8 Health, Safety & Environment	95,1%	88,1%	17	2

Dany Julien (2019)

4.3.9.7. Enriched Level III Metrics: Project Controls

Project Controls also performed well in this enriched model. The “Earned and Burned Indicators” (88.2%) was the top metrics in this enriched model, just ahead of the “Health, Safety and Environment” (88.1%) metric, which belonged to the EPCM Agility’s performance attribute. The only Project Controls’ Level III metric that did not perform well in this model was also a procurement type metric, known as “Cost to Execute Purchase Orders” (metric 9.2). In fact, this metric ended in the 5th tier of the enriched model and will not be introduced during the survey. In total, the Project Controls’ Level III metrics contains fifty-one (51) enriched Level III metrics. The researcher’s findings are illustrated in Table 4.75.

Table 4. 75
Enriched Level III Metrics: Project Controls

Perf. Attribute: Project Controls		Robustness	Overall Ranking	Tiers 1-5	Category Ranking
TOP 12	Enriched Level III Metrics				
1	6.2 Earned and Burned Indicators	88,2%	1	1	1
2	6.1 Budget (Acutal vs. EAC)	87,5%	3	1	2
3	7.1 Labour (+ Management) Spends	86,9%	4	1	3
4	7.2 Equipment + Materials Spends	86,6%	6	1	4
5	7.3 Rework Spends	86,3%	7	1	5
6	8.3 Warehouse / Laydown Spends	83,6%	16	2	6
7	8.4 Inventory Carrying Costs Spends	83,6%	17	2	6
8	8.1 Transportation Spends	83,6%	18	2	6
9	7.4 IT Integration Spends	83,6%	19	2	6
10	8.2 Customs Spends	82,7%	26	3	7
11	9.1 Suppliers Spends	80,2%	35	4	8
12	9.2 Costs to Execute Purchase Orders	77,8%	48	5	9

Enriched SCOR Model						Category Ranking
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	6. Budget & Planning	89,5%	Robustness	# of metrics	
	88,4%	6.1 Budget (Acutal vs. EAC)	88,4%	87,5%	5	3
		6.2 Earned and Burned Indicators	90,6%	88,2%	3	1
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	7. LEM Spends	84,8%	Robustness	# of metrics	
	87,1%	7.1 Labour (+ Management) Spends	87,9%	86,9%	4	4
		7.2 Equipment + Materials Spends	87,1%	86,6%	5	6
		7.3 Rework Spends	86,2%	86,3%	4	7
		7.4 IT Integration Spends	78,1%	83,6%	4	19
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	8. Logistics Spends	82,8%	Robustness	# of metrics	
	81,7%	8.1 Transportation Spends	83,5%	83,6%	6	18
		8.2 Customs Spends	80,8%	82,7%	2	26
		8.3 Warehouse / Laydown Spends	83,5%	83,6%	2	16
		8.4 Inventory Carrying Costs Spends	83,5%	83,6%	7	17
4	Enriched Performance Attribute: Project Control		Level II	Level III		
85,7%	Level 1	9. Procurement Spends	75,4%	Robustness	# of metrics	
	75,9%	9.1 Suppliers Spends	79,0%	80,2%	6	35
		9.2 Costs to Execute Purchase Orders	71,9%	77,8%	3	48

Dany Julien (2019)

4.3.9.8. Enriched Level III Metrics: Workers Management

Although several participants recognized the importance of the performance attribute Workers (Employees) Management, these enriched Level III metrics performed poorly in terms of their robustness during the semi-structured interviews. Both Level II /III metrics (10.1 and 10.2) terminated in the 5th tier and subsequently, will not be introduced to the participants taking parts of the survey. Thus, twelve (12) Level III metrics will be taken off from the initial 366 KPIs presented at the beginning of the semi-structured surveys. The researcher's findings are illustrated in Table 4.76.

Table 4. 76
Enriched Level III Metrics: Workers (Employees) Management

Perf. Attribute: Workers (Employees) Management		Robustness	Overall Ranking	Tiers 1-5	Category Ranking
TOP 3	Enriched Level III Metrics				
1	10.1 Labour Force's Personal Information	79,2%	46	5	1
2	10.2 Management Staff's Personal Information	79,0%	47	5	2

Enriched SCOR Model						Category Ranking
5	Enriched Performance Attribute: Workers (Employee) Management		Level II	Level III		
81,3%	Level 1	10. Workers (Employee) Information	77,5%	Robustness	# of metrics	
	78,6%	10.1 Labour Force's Personal Information	77,7%	79,2%	7	46
		10.2 Management Staff's Personal Information	77,2%	79,0%	5	47

Dany Julien (2019)

4.3.9.9. Enriched Level III Metrics: Project Complexity

Level III metrics which belong to the performance attribute of Project Complexity also performed poorly during the interviews. Participants pointed the importance of "Job-Site Complexity", which the metrics ended up in the 3rd tier. The sites' metrics are usually construction driven. On the other hand, the "Off-Site Complexity" Level III metrics finished last, in the 5th tier. The activities for "Off-Site Complexity" are considered important in the eyes of supply chain staffs, however, it showed a level of non-importance for the overall participants that took part in the interviews. The low robustness for these metrics is an example that displays the dominance of the engineering and construction culture during mega-projects; and the lower appreciation for supply chain metrics.

Project Complexities include seventy-nine (79) Level III metrics, of which only 12.1 and 12.2 (Job-Site Complexities) will be put forward in the survey test. The researcher's findings are illustrated in Table 4.77 with the ranking of Level III metrics pertaining to Project Complexity's On-Site and Off-Site.

Table 4. 77
Enriched Level III Metrics: Project Complexity

Perf. Attribute: Project Complexity		Robustness	Overall Ranking	Tiers 1-5	Category Ranking
TOP 6	Enriched Level III Metrics				
1	12.1 Contractor Base Complexity	**83,5%**	22	3	1
2	12.2 Management Team / Owner Represetatives	**82,9%**	25	3	2
3	11.2 Distribution Complexity	**79,9%**	42	5	3
4	11.1 Manufacturing Complexity	**79,6%**	43	5	4
5	11.3 Supplier Base Complexity	**79,6%**	44	5	4
6	11.4 IT Base Complexity	**77,8%**	49	5	5

Enriched SCOR Model						Category Ranking
6	**Enriched Performance Attribute: Project Complexity**		**Level II**	**Level III**		
	Level 1	**11. Off-Site Complexity**	**74,8%**	**Robustness**	**# of metrics**	
81,7%	**81,3%**	11.1 Manufacturing Complexity	**75,9%**	**79,6%**	2	43
		11.2 Distribution Complexity	**76,8%**	**79,9%**	9	42
		11.3 Supplier Base Complexity	**75,9%**	**79,6%**	3	44
		11.4 IT Base Complexity	**70,5%**	**77,8%**	5	49
6	**Enriched Performance Attribute: Project Complexity**		**Level II**	**Level III**		
	Level 1	**12. Job Site Complexity**	**83,0%**	**Robustness**	**# of metrics**	
81,7%	**84,8%**	12.1 Contractor Base Complexity	**83,9%**	**83,5%**	47	22
		12.2 Management Team / Owner Represetatives	**82,1%**	**82,9%**	13	25

Dany Julien (2019)

4.3.9.10. Enriched Level III Metrics: Project Integration

The last set of Level III metrics analysed during the semi-structured interviews pertained to the performance attributes called Project Integration. Amongst these metrics, participants ranked the Level III metrics in the 4th tier. From their recorded remarks, participants had devising and opposite views on the need to conduct analytics during, particularly, the construction phase. In general, the younger participants favored such approach, whereas the more experimented managers cautioned the researcher in sinking a project in too much details, nor they had the manpower to exercise such detailed reports, and the relation between profiling and privacy.

There were only five (5) Level III metrics in the performance attributes of Project Integration. Only the metrics 13.2 and 13.2 will be tested during the survey. The researcher's findings are illustrated in Table 4.78 with the ranking of Level III metrics pertaining to Project Integration.

Table 4. 78
Project Integration Level III Metrics

Perf. Attribute: Project Integration		Robustness	Overall Ranking	Tiers 1-5	Category Ranking
TOP 3	Enriched Level III Metrics				
1	13.3 Performance Analytics	80,4%	34	4	2
2	13.1 Level II Metrics	79,9%	40	5	3
3	13.2 Level III Metrics	81,3%	31	4	1

Enriched SCOR Model						Category Ranking
7	Enriched Performance Attribute: Project Integration		Level II	Robustness	# of metrics	
84,4%	Level 1	13. Performance Anaytics	80,6%	N/A	N/A	
	77,2%	13.1 Level II Metrics	79,9%	80,5%	1	40
		13.2 Level III Metrics	81,3%	81,0%	1	31
		13.3 Performance Analytics	81,3%	80,4%	3	34

Dany Julien (2019)

4.3.10. Project Phases Integrations

In the last section of the semi-structured interviews, the participants were asked to grade from 1 to 5 the importance of each performance attribute during the five (5) phases of construction project management. In general, the importance of timeline for specific phase during mega-projects appears to follow logic, where as a project move forward from conceptual to construction, the phases scored higher in importance. For instance, the conceptual phase scored 266, whereas the construction scored 728.

Secondly, when measuring the importance of performance attributes in relation to the timeline for a specific phase, Project Controls still dominated in mega-projects, like Level I, II and III metrics. Table 4.79 illustrates the results for the project phases' integration. The interpretations of the results are described below

Table 4. 79
Project Phases Integration

0 = No need to measure	
1 = little importance to measure	
2 = Sometimes important to measure	
3 = Should be measured	
4 = Important to measure	

Enriched SCOR Model Project Phases Integrations		Conceptual	Front-End Planning	Detailed Engineering	Construction	
no	Enriched Performance Attributes	1 to 5	1 to 5	1 to 5	1 to 5	Total Score
1	Procurement Reliability	18	50	117	122	307
2	Procurement Responsiveness	17	45	103	121	286
3	EPCM Agility	45	89	106	126	366
4	Project Controls	83	102	115	130	430
5	Workers Management	29	58	87	123	297
6	Project Complexity	74	110	107	106	397
7	Project Integration	N/A	N/A	N/A	N/A	
	Total Score	266	454	635	728	

Dany Julien (2019)

4.3.10.1. Conceptual Phase

Planning for the Conceptual Phase, in terms of timeline, occurs three (3) to five (5) years before the beginning of the construction phase. It makes sense to project owners to understand right from the start, if a project is too complex (On-Site Complexities) and costly (Project Controls). During the Conceptual Phase, participants ranked Project Controls' metrics as the most important, with a score of 83 (not robustness). Participants in the semi-structured interviews considered the importance of measuring the cost of the project with the highest accuracy possible, right from the start of a project.

A surprising result in 2nd place was that participants considered Project Complexity (score of 74) over EPCM Agility (score of 45). Although, Off-Site Complexities performed poorly during the semi-structured interviews, while expressing low robustness scores for its Level III metrics, the participants acknowledged the importance of understanding "Off-Site Complexities", as an essential part of planning, but unnecessary need to quantify them during construction.

The performance attribute of Workers (Employee) Management finished 4th with a low score of 29, ahead of both procurement reliability (18) in 5th place and procurement responsiveness (17) terminating last in 6th place. Similar to the first residency where a Participant Observation methodology was used to measure the importance of supply chain activities, the Conceptual Phase did not demonstrate a high level of affinity for these activities.

4.3.10.2.Front-End Planning

Metrics belonging to Project Complexity (Off-Site and Job-Site) came in 1st place with a score of 110 during the Front-End Planning; ahead of Project Controls' metrics in 2nd place with a score of 102. Although appreciated as an important performance attribute by the participants in the interviews, Level III metrics related to Off-Site Complexities were not retained for the survey.

Considering the Front-End Planning phase, in terms of time line, occurs between two (2) to three (3) years before the beginning of the construction phase, project planners are trying to understand and to predict any potential complex issues before pursuing the final drawing in the detailed engineering phase. Therefore, it makes sense to consider Project Complexities as an important performance attribute and costing them appropriately.

EPCM Agility's metrics came in a strong 3rd place with a score of eighty-nine (89), not too far from Project Controls. Similar to the previous phase (Conceptual), Workers (Employee) Management, Procurement Reliability, and Procurement Responsiveness came 4th, 5th and 6th place, with a score of fifty-eight (58), fifty (50) and forty-five (45) respectively.

4.3.10.3.Detailed Engineering

During the Detailed Engineering Phase, Procurement Reliability's metrics came 1st with a score of 117, followed closely in 2nd place by Project Controls' metrics right behind with a score of 115. The jump in score for Procurement Reliability's metrics from 5th place during the Front-End Planning to a 1st place in Detailed Engineering, marks the importance of procuring long lead items during this phase. Henceforth, having strong supply chain procedures in place two (2) years before the starts of construction are seen important by the participants' scores.

Project Controls' metrics remain once again, very important for the participants that took part in the semi-structured interviews. Project Complexity (score of 107) and EPCM Agility (score of 106) were also rated by the participants as important metrics to be measured during the Detailed Engineering Phase. Although the speed of the Procurement Responsiveness' metrics during the Detailed Engineering Phase is not a priority, this research noted a jump in score, finishing in 5th place with a score of 103, versus a previous score of 45 during the Front-End Planning Phase. This jump in position reflects the importance of both procurement's metrics (reliability and responsiveness) during the Detailed Engineering phase, where long lead equipment and materials will be ordered and short lead materials will be planned with the construction department.

Finally, the Workers (Employee) Management's metrics finished last, in 6th place, with a score of eighty-seven (87), but illustrates the increase in importance from the previous phase (Front-End Planning) with a previous score of fifty-eight (58).

4.3.10.4.Construction

The Construction Phase shows different results from the previous phase. In 1st place with a score of 130, is again the performance attribute of Project Controls. This result states the importance of controlling cost, production and performance during mega-projects.

The 2nd place during Construction Phase is EPCM Agility with a score of 126. The performance of EPCM Agility is very important during the Construction Phase, since it covers all essential activities in engineering, site procurement and construction management.

The 3rd place was the performance attribute of Workers (Employee) Management with a score of 123. Although several participants recognized the importance of this performance attribute during construction, however, Level III metrics performed poorly in terms of ranking its robustness during the interviews.

Procurement Reliability and Responsiveness finished in 4th and 5th place with also a high score of 122 and 121 respectively. The participants noted the importance of long lead ordering and field procurement. Finally, the metrics belonging to the performance attribute of Project Complexity finished, in last, or 6th place with a score of 106. Similar results were obtained during the semi-structured interviews. The score in the Detailed Engineering Phase was like the Front-End Planning Phase with a score of 107. Once again, the participants reinstated their statements that job complexities should be measured prior to construction.

4.3.11. Conclusion – Semi-structured Interviews

In terms of robustness ranking, the first tier (1 to 10) of the Level III metrics are dominated by performance attributes belonging to Project Controls and EPCM Agility. When considering the top 20 Level III metrics, nine (9) of metrics belong to Project Controls' and eleven (11) of them were classified in the performance attributes of EPCM Agility. Hence, this research shows strong evidence that Level II/III metrics belonging to the performance attributes of Project Controls and EPCM Agility were the most important metrics for this enriched model.

On the other hand, the supply chain metrics belonging to procurement related activities did not performed well during these semi-structured interviews. For instance:

- Procurement Reliability & Responsiveness: Only one (1) Level III metrics (2.3 – Time to Respond to Procurement Inquiries) performed in the top 30. Otherwise, three (3) Level III metrics finished in the 5th tier and were removed from the survey. The metrics that were removed are: 1.1, 1.2 and 1.3;

- EPCM Agility: All Level III metrics have performed well in terms of overall robustness except for its procurement related metrics (4.6 – Reverse Logistics) that was locked down in the 4th tier. All EPCM Agility's Level III metrics were put forward in the survey test;

- Project Controls: Some of the Level III metrics had the strongest performance during the interviews. However, another procurement related metrics called (9.2) "Cost to Execute Purchase Orders" (9.2) ended up in the 5th tier and will be removed from the survey;

- Workers Management: Both Level III metrics finished in the 5th tier and will be not be introduced to the survey;

- Project Complexities: The Job-Site Complexities (12.1, 12.2) fair well in the interviews by ranking both in the 3rd tier. Contractors' congestion and drawing complexities were important to participants in the interviews. On the other hand, Off-Site Complexities (11.1, 11.2, 11.3 and 11.4) performed poorly and finished in the 5th tier, showing their non-importance by the participants during construction. However, the activities dealing with Off-Site Complexities remained important throughout the project, for any supply chain staffs.

The low robustness of procurement or supply chain metrics are evidences that displays the dominance of the engineering and construction culture during mega-projects. In terms of project integration throughout all phases, the researcher notes the following results:

- Procurement Reliability and Responsiveness were most important during the Detailed Engineering and Construction Phases;

- EPCM Agility was seen to be important during the Front-End Planning Phase and lasted throughout the project, thru Detailed Engineering and Construction;

- Project Controls was the most important attribute for all participants in the interviews and project phase integration with a score of 430;

- Workers Management started to gain strength at the end of Detailed Engineering and become essential during the Construction Phase;

- Participants viewed Project Complexities' performance attributes as essential throughout the project, with an understanding that Off-Site Complexities is important during Detailed Engineering and On-Site Complexity during the Construction.

Finally, Level III metrics that scored the lowest robustness level and terminated in the 5th tier (39-49) of this model were removed from the list presented to the participants that took part in the survey. Section 4.3.9.3 illustrates these sixty-one (61) Level III metrics that were removed from the enriched SCOR Model and introduced to the participants of the survey.

In conclusion, the enriched SCOR Model was minimised by sixty-one (61) Level III metrics and allowed the researcher to introduce the Modified SCOR Model to the survey's participant. The make-up of the Modified SCOR Model is illustrated in Table 4.79.

Table 4. 80
Project Phases Integration

	SCOR Model	Enriched SCOR Model	Modified SCOR Model
Performance Attributes (Quantitative)	5	7	5
Performance Attributes (Qualitative)	2	0	1
Level I Metrics	10	13	11
Level II Metrics	27	49	38
Level III Metrics	250	366	305

Dany Julien (2019)

4.4. SURVEY

A period of approximately 45 to 60 days lapsed between the interviews and the survey. Time to analyse the interviews' answers were needed by the researcher. Survey were sent to the original twenty-eight (28) participants of the interviews, and to one (1) more participant that was working overseas (Niger, France and Kazakhstan) at the time of the survey. From the twenty-nine (29) participants, only twenty-three (23) of them responded to the web-base survey (Survey Monkey). Three (3) reminders, such as emails and voice mails were sent to the five (5) participants that did not reply for taking part in the survey. The researcher had no success with them into pursuing the survey, and subsequently abandoned the last five (5) participants.

The first step of the survey was to introduce to the participants all top 4th tier Level II/ III metrics obtained from the semi-structured interviews, which accounted for thirty-eight (38) metrics. However, metric 13.2 (Level II metrics) was removed by the researcher due to some level of confusion expressed by the participants during the survey. Henceforth, a total of thirty-seven (37) metrics were surveyed through the electronic web-based Survey Monkey. Table 4.80 illustrates the thirty-seven (37) metrics that were ranked during the semi-structured interviews:

Table 4. 81
Modified SCOR Model

Modified SCOR Model - Survey			Category Ranking
1	**Enriched Performance Attribute: Procurement Reliability**		
81,3%	Level 1	**1. Delivery Performance**	
	80,8%	1.3 Perfect Orders' Fulfillment Arriving at Construction Site	37
		1.4 Purchase Orders' Quality & Accuracy	32
		1.5 Invoices' Accuracy	36
2	**Enriched Performance Attribute: Procurement Responsiveness**		
82,6%	Level 1	**2. Purchase Order Fulfilment**	
	80,4%	2.1 Time to Complete Purchase Order Entries	33
		2.3 Time to Respond to Procurement Inquiries	30
3	**Enriched Performance Attribute: EPCM Agility**		
81,3%	Level 1	**3. Engineering**	
	82,1%	3.1 Engineering Changes Orders	13
		3.2 Engineering Drawing Changes	23
		3.3 Engineering RFI	20
		3.4 Engineering Reworks & NCR	11
3	**Enriched Performance Attribute: EPCM Agility**		
81,3%	Level 1	**4. Procurement**	
	84,8%	4.1 Material Management at Site	15
		4.2 Transportation Management	27
		4.3 Leased Equipment Used at Site	21
		4.4 Inventory Management	24
		4.5 Bagging / Free Issue to Contractos / Expediting at Site	28
		4.6 Reverse Logistics (Auction, Surplus, Obsolete)	38
3	**Enriched Performance Attribute: EPCM Agility**		
81,3%	Level 1	**5. Construction Management**	
	87,1%	5.1 Schedule (FIWP) Development	8
		5.2 Schedule Changes	5
		5.3 Construction Site Performance	9
		5.4 Turnover & Commissioning	14
81,3%	87,9%	5.5 Document Control	11
		5.6 IT Integration Issues & Solving	29
		5.7 Contract / Labour Issues & Solving	10
		5.8 Health, Safety & Environment	2
4	**Enriched Performance Attribute: Project Control**		
85,7%	Level 1	**6. Budget & Planning**	
	88,4%	6.1 Budget (Acutal vs. EAC)	3
		6.2 Earned and Burned Indicators	1
4	**Enriched Performance Attribute: Project Control**		
85,7%	Level 1	**7. LEM Spends**	
	87,1%	7.1 Labour (+ Management) Spends	4
		7.2 Equipment + Materials Spends	6
		7.3 Rework Spends	7
		7.4 IT Integration Spends	19
4	**Enriched Performance Attribute: Project Control**		
85,7%	Level 1	**8. Logistics Spends**	
	81,7%	8.1 Transportation Spends	18
		8.2 Customs Spends	26
		8.3 Warehouse / Laydown Spends	16
		8.4 Inventory Carrying Costs Spends	17
4	**Enriched Performance Attribute: Project Control**		
85,7%	Level 1	**9. Procurement Spends**	
	75,9%	9.1 Suppliers Spends	35
5	**Enriched Performance Attribute: Workers (Employee) Management**		
6	**Enriched Performance Attribute: Project Complexity**		
	Level 1	**12. Job Site Complexity**	
81,7%	84,8%	12.1 Contractor Base Complexity	22
		12.2 Management Team / Owner Represetatives	25
7	**Enriched Performance Attribute: Project Integration**		
84,4%	Level 1	**13. Performance Anaytics**	
	77,2%	13.3 Performance Analytics	34

Dany Julien (2019)

A similar Likert scale was presented to the participants, but in reverse order from the interviews' rankings. For instance:

- If a participant strongly agreed with a performance attributes/metrics being measured, the highest score of "1" was attributed;
- When a participant agreed in the performance attributes/metrics being measured in construction mega-projects, the score of "2" was assigned;
- When the participants were undecided toward the performance attributes/metrics being useful in construction mega-projects, a score of "3" was given;
- If the participants disagreed with a performance attribute/metrics being measured, a score of "4" was attributed;
- If the participants strongly disagreed with the performance attributes/metrics being measured during construction mega-projects, the lowest score of "5" was assigned.

The next step of the survey was to calculate the robustness of each performance attributes, Level I, II and III metrics. Then, once the levels of robustness were calculated, the researcher grouped the thirty-seven (37) Level II/III into five (5) tiers:

a) 1st tier was the Modified SCOR Model Level II/II metrics that achieved the ranking of 1 to 7;
b) 2nd tier was the Modified SCOR Model Level II/II metrics with the ranking between 8 and 14;
c) 3rd tier was the Modified SCOR Model Level II/II metrics with the ranking between 15 to 21;
d) 4th tier was the was Modified SCOR Model Level II/II metrics with the ranking between 22 and 28, and lastly;
e) the 5th tier was Modified SCOR Model Level II/II metrics with the ranking score between 29 and 37.

Finally, the last process was to test the Level II/III metrics against participants' perception during four types of construction. This last test resulted in going from a

Modified SCOR Model into the final artefact, named Construction Performance & Productivity Model (CPPM). Familiar with the interviews, the participants in the survey were instructed to score each metrics in order of importance, as presented above. In addition, participants had to score the Modified SCOR Model's performance attributes/metrics while assuming the role of either: a) an owner, b) a contractor, c) operating under a Lump Sum contract, or d) operating under a Time & Materials contract. Hence, the last thirty-seven (37) Level II/III metrics were presented with four (4) question categories:

- Q1. When Owners are constructing mega-projects ($300M+) and operating under "LUMP SUM / DESIGN BUILT CONTRACT", which metrics would you consider measuring?

- Q2. When Owners are constructing mega-projects ($300M+) and operating under "TIME MATERIALS / COSTS +% CONTRACT", which metrics would you consider measuring?

- Q3. When Contractors are constructing mega-projects ($300M+) and operating under "LUMP SUM / DESIGN BUILT CONTRACT", which metrics would you consider measuring?

- Q4. When Contractors are constructing mega-projects ($300M+) and operating under "TIME MATERIALS / COSTS +% CONTRACT", which metrics would you consider measuring?

The way that robustness was calculated in the survey is as followed: For instance, the Level II/III metrics 6.2 had a robustness of 88.2% during the interviews and had a score of 2.04 in the survey (1 = strongly agreed and 5 = strongly disagreed). Here, in this example, a total score for the twenty-three (23) participants were added up, then averaged out, and ranked overall, as it is demonstrated below in Table 4.81.

Table 4. 82
General Survey Calculations

		Interview				Participants Codes																							Survey				
Perf. Attributes	Level II / III Metrics	Robust.	Category Ranking	Overall Ranking	Tiers 1-5	1	2	3	4	7	8	9	11	12	13	14	15	17	19	21	22	26	27	32	33	42	47	51	Total	Count	Average	Q1 Ranking	Tiers 1-5
Project Control	6.2 Earned and Burned Indicators	**88,2%**	1	1	1	4	1	2	4	2	1	2	2	2	2	1	5	2	2	3	1	2	2	2	1	1	2	1	47	23	2,04	21	3

Dany Julien (2019)

The results of the robustness for each metric, which was responded by the participants in the survey (1 to 5) differ from the level robustness for the same metric obtained during the interviews (0-100%). At the end, the robustness levels obtained in the survey were sub-divided into five (5) tiers, like the interview process.

4.4.1. Question 1: Owner / Lump Sum Contract

When Owners are constructing mega-projects ($300M+) and operating under "LUMP SUM / DESIGN BUILT CONTRACT", which metrics would you consider measuring?

The lump sum contract is an agreement by project owners to pay contractors a fixed price upon completion, regardless of the costs incurred to the contractors. Because the contractors assume all the cost, the owners will be less pre-occupied to manage cost control, productivity and/or the actual profits or losses incurred by the contractors. Changes in the contract requirements requested or caused by the owners or prime contractors may be used to modify the fixed price (Benton et al., 2010).

4.4.1.1. 1st Tier Level III Metrics

The researcher's findings for 1st tier (1-7) metrics when working under Owner - Lump Sum Contracts are illustrated in Table 4.82 below, and respect the contractual thinking of the lump sum contract's objectives: Owners worry more about performance in engineering, procurement and construction management, than the fixed costs for the project that is already agreed by both parties.

Table 4. 83
Level III Metrics 1st Tier – Owner / LS Contract

			Interview			Owner LS		
						Q1 - Score	Q1 Ranking	Tier 1 to 5
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	1	R	T
EPCM Agility	5.8 Health, Safety & Environment	**88.1%**	1	2	1	**1.22**	1	1
EPCM Agility	5.2 Schedule Changes	**86.8%**	2	5	1	**1.32**	3	1
EPCM Agility	5.1 Schedule (FIWP) Development	**85.7%**	3	8	1	**1.50**	7	1
EPCM Agility	3.4 Engineering Reworks & NCR	**83.9%**	6	12	2	**1.30**	2	1
EPCM Agility	3.1 Engineering Changes Orders	**83.9%**	6	13	2	**1.39**	5	1
EPCM Agility	5.4 Turnover & Commissioning	**83.9%**	6	14	2	**1.48**	6	1
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	**79.9%**	6	37	4	**1.35**	4	1

Dany Julien (2019)

- Six (6) out of (7) metrics during the Owner - Lump Sum Contracts were amongst the performance attributes of EPCM Agility. It correlates with Benton *et al*. (2010) where lump sum contracts are best suited to situations where the scope of work and specifications are well defined. Hence, engineering, procurement and construction management metrics are important during an Owner – Lump Sum Contract;

- Metric 5.8 Health, Safety & Environment finished 1st overall in both the interviews and the survey, providing evidence that safety is the number one concern to all parties working in a construction site;

- Three (3) metrics (5.1, 5.2, and 5.8) finished in the 1st tier during both interviews and with the Owner Lump Sum Contracts;

- Three (3) metrics (3.1, 3.4, and 5.4) had finished in the 2nd tier during the interviews but now ranked in the 1st tier of importance during an Owner - Lump Sum Contracts;

- Metric 1.1 (Delivery Performance against Requested Date) jumped from the 4th tier during the interviews to the 1st tier of importance when dealt with the Owner - Lump Sum Contracts. Meeting dates of deliveries are still important for Owners, even though a fixed price has been agreed.

4.4.1.2. 2nd Tier Level III Metrics

The researcher's findings for 2nd tier (8-14) metrics when working under Owner - Lump Sum Contracts are illustrated in Table 4.83, with a mixture of metrics belonging to several performance attributes, but still dominated by the EPCM Agility.

Table 4. 84
Level III Metrics 2nd Tier – Owner / LS Contract

Perf. Attributes	Level II / III Metrics	Robustness	Interview Category Ranking	Interview Overall Ranking	Interview Tiers 1-5	Owner LS Q1 - Score (1)	Owner LS Q1 Ranking (R)	Owner LS Tier 1 to 5 (T)
Project Control	6.1 Budget (Acutal vs. EAC)	87.5%	2	3	1	1.65	10	2
EPCM Agility	5.5 Document Control	84.2%	5	11	2	1.86	14	2
EPCM Agility	4.1 Material Management at Site	83.8%	7	15	2	1.74	11	2
EPCM Agility	5.3 Engineering RFI	83.6%	9	20	2	1.78	12	2
EPCM Agility	3.2 Engineering Drawing Changes	83.3%	10	23	3	1.52	8	2
Employee Management	13.3 Performance Analytics	80.4%	1	33	4	1.83	13	2
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	80.2%	4	35	4	1.61	9	2

Dany Julien (2019)

- Metrics belonging to the performance attributes of EPCM Agility still dominate this 2nd tier, with four (4) metrics out of seven (7) belong to it;

- The metric 6.1 Budget (Actual vs. EAC) which finished in the 1st tier during the interviews was ranked 10th overall when working under Owner - Lump Sum Contracts. Although the contractors are responsible for all the costs, the owners still have an interest to know the financial health of the contractors during the project, however, this metric is not a priority (top 1st tier);

- Two (2) metrics that showed lower robustness level in the 4th tier during the interview, finished 9th (1.5 - Invoice Accuracy) and 13th (13.3 – Performance Analytics) when working under Owner - Lump Sum Contracts. Although prices are fixed during Lump Sum contract, the owners are still keen to receive accurate invoices based on earned payment.

4.4.1.3. 3rd Tier Level III Metrics

The researcher's findings for 3rd tier (15-21) metrics when working under Owner - Lump Sum Contracts are illustrated in Table 4.84. The performance attribute of Project Controls metrics had the most metrics in this tier.

Table 4. 85
Level III Metrics 3rd Tier – Owner / LS Contract

		Interview				Owner LS		
						Q1 - Score	Q1 Ranking	Tier 1 to 5
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	1	R	T
Project Control	6.2 Earned and Burned Indicators	**88.2%**	1	1	1	**2.04**	21	3
Project Control	7.1 Labour (+ Management) Spends	**86.9%**	3	4	1	**2.00**	17	3
Project Control	7.2 Equipment + Materials Spends	**86.6%**	4	6	1	**2.00**	18	3
EPCM Agility	5.3 Construction Site Performance	**85.7%**	3	9	1	**2.00**	19	3
EPCM Agility	5.7 Contract / Labour Issues & Solving	**84.8%**	4	10	1	**1.95**	15	3
Project Complexity	12.2 Management Team / Owner Representatives	**82.9%**	2	25	3	**1.96**	16	3
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	**81.4%**	1	30	4	**2.00**	20	3

Dany Julien (2019)

- Metrics belonging to the performance attributes of Project Controls and EPCM Agility, which were in the 1st tier for their robustness levels during the interviews dominate the 3rd tier metrics when working under Owner -Lump Sum Contracts;

- For the first time, the metric (12.2 – Management Team / Owner Representative) belonging to the performance attribute of Project Complexity appeared in this tier;

- Similar to the first two tiers, the 3rd tier also displayed a metric (2.3 – Time to Respond to Procurement Inquiries) which belong to the performance attributes of Procurement Reliability & Responsiveness.

4.4.1.4. 4th and 5th Tier Level III Metrics

The 4th and 5th (22-37) represent the last set of metrics when working under Owner - Lump Sum Contracts. The researcher's findings are illustrated in Table 4.85. Appendix K illustrates the results for Q1- Survey.

- The metric 7.3 (Rework Spends) which finished in the 1st tier during the interview surprisingly finished in the 4th tier under the Owner - Lump Sum Contracts. The researcher has no explanation for the poor performance of this metric, as it is an important one during the Closed-Out Phase.

- The metric 4.5 (Bagging / Free Issue) top the 4th tier metrics, followed by two (2) metrics (1.4, 2.1) belonging to the performance attributes of Procurement Reliability & Responsiveness;

- Metrics belonging to the performance attributes of Project Controls and EPCM Agility dominate the 4th and 5th tier.

Table 4. 86
Level III Metrics 4th and 5th Tier – Owner / LS Contract

Perf. Attributes	Level II / III Metrics	Robustness	Interview Category Ranking	Interview Overall Ranking	Interview Tiers 1-5	Owner LS Q1 - Score (1)	Owner LS Q1 Ranking (R)	Owner LS Tier 1 to 5 (T)
Project Control	7.3 Rework Spends	**86.3%**	5	7	1	**2.14**	26	4
Project Control	8.3 Warehouse / Laydown Spends	**83.6%**	6	16	2	**2.32**	28	4
Project Control	8.4 Inventory Carrying Costs Spends	**83.6%**	6	17	2	**2.30**	27	4
Project Control	8.1 Transportation Spends	**83.6%**	6	18	2	**2.32**	29	5
Project Control	7.4 IT Integration Spends	**83.6%**	6	19	2	**2.65**	36	5
EPCM Agility	4.3 Leased Equipment Used at Site	**83.6%**	9	21	3	**2.39**	30	5
Project Complexity	12.1 Contractor Base Complexity	**83.5%**	1	22	3	**2.43**	31	5
EPCM Agility	4.4 Inventory Management	**83.0%**	11	24	3	**2.09**	25	4
Project Control	8.2 Customs Spends	**82.7%**	7	26	3	**2.52**	34	5
EPCM Agility	4.2 Transportation Management	**82.7%**	8	27	3	**2.48**	33	5
EPCM Agility	4.5 Bagging / Free Issue to Contractos / Expediting at Site	**82.1%**	12	28	3	**2.04**	22	4
EPCM Agility	5.6 IT Integration Issues & Solving	**81.8%**	13	29	3	**2.43**	32	5
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy	**81.0%**	2	31	4	**2.04**	23	4
Procur. Reliability & Responsiveness	2.1 Time to Complete Purchase Order Entries	**80.8%**	3	32	4	**2.09**	24	4
Project Control	9.1 Suppliers Spends	**80.2%**	8	34	4	**2.57**	35	5
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	**80.1%**	14	36	4	**2.70**	37	5

Dany Julien (2019)

4.4.2. Question 2: Owner / Time Materials Contract

When Owners are constructing mega-projects ($300M+) and operating under "TIME MATERIALS / COSTS + % CONTRACT", which metrics would you consider measuring?

The choice of contract type is closely related to the magnitude of risks associated with the scope of work to accomplish during a project. In the case of Time Materials / Cost + /% Contract, these types of contracts are used where the scope of work is uncertain. Contractors have some leniencies in completing works as they are being paid under time and materials, due to undefined scope of work. As an example, lateness in the completion of design drawings would be highly risky for contractors to take up projects, as costs for time labour and materials can easily become out of control if you were to agree into a fixed price.

In this type of contract, the owner will pay the prime contractor for costs (labour and materials) incurred in construction plus some sort of additional fees (%) agreed in principal. The fees in percentage (%) will vary in terms of labour and materials. Here, in this type of contract, the owners are vulnerable to contractors for any rate increase, as amended in a contract.

4.4.2.1. 1st Tier Level III Metrics

The researcher's findings for 1st tier (1-7) metrics when working under Owner - Time Materials / Cost + % Contract are illustrated in Table 4.86. The metrics that were ranked in the 1st tier respect the contractual thinking of owners wishing to control project costs as their first objective, since contractors have a less constringent time to get invoice approved. Thus, the metrics under Project Controls will be prevalent in this type of contract.

Table 4. 87
Level III Metrics 1st Tier – Owner / T&M Contract

			Interview			Owner T&M		
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	2 (Q2 Score)	R (Q2 Ranking)	T (Tier 1 to 5)
Project Control	6.2 Earned and Burned Indicators	**88.2%**	1	1	1	**1.18**	1	1
EPCM Agility	5.8 Health, Safety & Environment	**88.1%**	1	2	1	**1.27**	2	1
Project Control	6.1 Budget (Acutal vs. EAC)	**87.5%**	2	3	1	**1.32**	3	1
Project Control	7.1 Labour (+ Management) Spends	**86.9%**	3	4	1	**1.36**	5	1
EPCM Agility	5.2 Schedule Changes	**86.8%**	2	5	1	**1.32**	4	1
Project Control	7.2 Equipment + Materials Spends	**86.6%**	4	6	1	**1.36**	6	1
EPCM Agility	3.4 Engineering Reworks & NCR	**83.9%**	6	12	2	**1.45**	7	1

Dany Julien (2019)

- When considering Owner - Time Materials / Cost + % Contract, the first sixth robustness metrics during the interviews were identical to the ones in the survey. These scores demonstrate a tremendous importance for the owners to control costs since the contractors has literally an opened-check book, if not followed stringently;

- Under this type of contract, the owners are concerned with the objective of controlling project costs, engineering schedules, changes and reworks, which are all related to cost increase;

- The metrics belonging to the performance attributes of Project Control and EPCM Agility are dominating the 1st tier ranking, when working under the Owner - Time Materials / Cost +% Contract.

4.4.2.2. 2nd Tier Level III Metrics

The researcher's findings for 2nd tier (8-14) metrics when working under Owner - Time Materials / Cost + % Contract are illustrated in Table 4.87, with predominantly metrics belonging to the performance attribute of EPCM Agility.

Table 4. 88
Level III Metrics 2nd Tier – Owner / T&M Contract

Perf. Attributes	Level II / III Metrics	Robustness	Interview Category Ranking	Interview Overall Ranking	Interview Tiers 1-5	Owner T&M Q2 Score	Owner T&M Q2 Ranking (R)	Owner T&M Tier 1 to 5 (T)
Project Control	7.3 Rework Spends	**86.3%**	5	7	1	**1.50**	9	2
EPCM Agility	5.1 Schedule (FIWP) Development	**85.7%**	3	8	1	**1.55**	10	2
EPCM Agility	3.1 Engineering Changes Orders	**83.9%**	6	13	2	**1.59**	12	2
EPCM Agility	4.1 Material Management at Site	**83.8%**	7	15	2	**1.68**	14	2
EPCM Agility	5.3 Engineering RFI	**83.6%**	9	20	2	**1.55**	11	2
EPCM Agility	4.4 Inventory Management	**83.0%**	11	24	3	**1.59**	13	2

Dany Julien (2019)

- Metrics belonging to the performance attribute of EPCM Agility still dominate this tier, with having six (6) metrics out of seven (7);
- The metric 7.3 (Rework Spends) is the only other performance attribute (Project Control) in the 2nd tier. This spends is also important to the owners as they want to know any extra costs, and who is contractually responsible to cover the costs.
- The metric 4.4 (Inventory Management) went from 24th level of robustness during the interview to a strong 13th position, when owners working under Time Materials / Cost + % Contract. This performance indicates the importance of controlling material costs during such a type of contract. In fact, surplus can be easily accumulated in a project, especially, near the end, when everyone is focused on completing the project at what ever costs it take.

4.4.2.3. 3rd Tier Level III Metrics

The researcher's finding for 3rd tier (15-21) metrics when working under Owner - Time Materials / Cost +% Contract are illustrated in Table 4.88.

Table 4. 89
Level III Metrics 3rd Tier – Owner / T&M Contract

			Interview			Owner T&M (Q2 Score)	Owner T&M (Q2 Ranking)	Owner T&M (Tier 1 to 5)
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	2	R	T
EPCM Agility	5.3 Construction Site Performance	**85.7%**	3	9	1	**1.77**	20	3
EPCM Agility	5.5 Document Control	**84.2%**	5	11	2	**1.77**	21	3
EPCM Agility	5.4 Turnover & Commissioning	**83.9%**	6	14	2	**1.73**	18	3
EPCM Agility	3.2 Engineering Drawing Changes	**83.3%**	10	23	3	**1.68**	15	3
Project Complexity	12.2 Management Team / Owner Representatives	**82.9%**	2	25	3	**1.73**	19	3
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	**81.4%**	1	30	4	**1.68**	16	3
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	**79.9%**	6	37	4	**1.68**	17	3

Dany Julien (2019)

- Metrics belonging to the performance attribute of EPCM Agility dominate this 3rd tier;

- The first metric (12.2 – Management Team / Owner Representative) belonging to the attribute of Project Complexity appeared in this 3rd tier, when working under Owner - Lump Sum Contracts;

- The two (2) metrics belonging to the performance attributes of Procurement Reliability & Responsiveness (2.3 and 1.1) demonstrate the importance of delivering materials at site on time, so to avoid any crew delays and labour cost increase.

4.4.2.4. 4th and 5th Tier Level III Metrics

The researcher's findings for 4th and 5th (22-37) metrics when working under Owner - Time Materials / Cost +% Contract are illustrated in Table 4.89. Appendix K illustrates the results for Q2 - Survey.

- Metric 5.7 (Contract / Labour Issues & Solving) was in the top 10th robustness during the interviews, however, it only ranked 25th in importance when working under Owner - Time Materials / Cost +% Contract. This low score doesn't make sense, especially in the costing dispute resolution where owners would argue against increase changes in labour and materials. In the eye of the researcher, this ranking for this metric is disappointing, but must be reported as it is found;

Table 4. 90
Level III Metrics 4th and 5th Tier – Owner / T&M Contract

			Interview			Owner T&M		
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	Q2 Score 2	Q2 Ranking R	Tier 1 to 5 T
EPCM Agility	5.7 Contract / Labour Issues & Solving	**84.8%**	4	10	1	**1.86**	25	4
Project Control	8.3 Warehouse / Laydown Spends	**83.6%**	6	16	2	**2.00**	31	5
Project Control	8.4 Inventory Carrying Costs Spends	**83.6%**	6	17	2	**1.95**	29	5
Project Control	8.1 Transportation Spends	**83.6%**	6	18	2	**1.91**	27	4
Project Control	7.4 IT Integration Spends	**83.6%**	6	19	2	**2.32**	35	5
EPCM Agility	4.3 Leased Equipment Used at Site	**83.6%**	9	21	3	**1.82**	22	4
Project Complexity	12.1 Contractor Base Complexity	**83.5%**	1	22	3	**2.45**	37	5
Project Complexity	8.2 Customs Spends	**82.7%**	7	26	3	**2.27**	34	5
EPCM Agility	4.5 Bagging / Free Issue to Contractos / Expediting at Site	**82.1%**	12	28	3	**1.95**	30	5
EPCM Agility	5.6 IT Integration Issues & Solving	**81.8%**	13	29	3	**2.33**	36	5
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy	**81.0%**	2	31	4	**1.86**	26	4
Procur. Reliability & Responsiveness	2.1 Time to Complete Purchase Order Entries	**80.8%**	3	32	4	**1.82**	23	4
Employee Management	13.3 Performance Analytics	**80.4%**	1	33	4	**1.82**	24	4
Project Control	9.1 Suppliers Spends	**80.2%**	8	34	4	**2.24**	33	5
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	**80.1%**	14	36	4	**2.18**	32	5

Dany Julien (2019)

4.4.3. Question 3: Contractor / Lump Sum Contract

When Contractors are constructing mega-projects ($300M+) and operating under "LUMP SUM / DESIGN BUILT CONTRACT", which metrics would you consider measuring?

The contractual agreement of the lump sum contract in Q1 and Q3 are identical, whereas a project owner will pay a contractor a fixed price upon completion, regardless of the costs incurred to the contractor. Because the contractor assumes all the cost, under an agreed lump sum, it will be very pre-occupied to manage cost control, productivity and the actual profits or losses incurred during the project.

4.4.3.1. 1st Tier Level III Metrics

The researcher's findings for 1st tier (1-7) metrics when working under Contractor – Lump Sum Contracts are illustrated in Table 4.90 and respect the contractual thinking of the lump sum contract's objectives, which are performance in engineering, procurement and construction management.

- Contractors whom bear all the risks, will make sure to control their project costs, when working under Contractor – Lump Sum Contracts. Therefore, metric 6.1

(Budget – Actual vs. EAC) which finished in 1st tier in Q3, compared to a 2nd tier finished in Q1. This is an evidence that when contractors are assuming all the costs and facing all risks in a Lump Sum contract, will want to control the projects' costs;

- Similar with Q1, the metric 5.8 (HSE) is also very important to the eyes of contractors, with a ranking of 1st overall;

- Metric 1.1 (Delivery Performance against Requested Date) jumped from the 4th tier during the interview to the 1st tier of importance in the Contractor – Lump Sum Contracts. Having materials delivered on time, ready for installation, go hand in hand during the Construction Phase;

- Metric 5.7 (Contract /Labour Issues & Solving) was highly important in the eyes of the contractors, since, they will be the ones arguing / disputing for any kind of rate increase due to engineering, procurement or construction changes. This metrics only rated in the 3rd tier of importance during the Q1 survey.

Table 4. 91

Level III Metrics 1st Tier – Contractor / LS Contract

		Interview				Contractor LS		
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	Q3 Score	Q3 Ranking	Tier 1 to 5
						3	R	T
EPCM Agility	5.8 Health, Safety & Environment	88.1%	1	2	1	1.19	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	87.5%	2	3	1	1.38	3	1
EPCM Agility	5.2 Schedule Changes	86.8%	2	5	1	1.43	5	1
EPCM Agility	5.1 Schedule (FIWP) Development	85.7%	3	8	1	1.38	4	1
EPCM Agility	5.3 Construction Site Performance	85.7%	3	9	1	1.43	6	1
EPCM Agility	5.7 Contract / Labour Issues & Solving	84.8%	4	10	1	1.33	2	1
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	79.9%	6	37	4	1.43	7	1

Dany Julien (2019)

4.4.3.2. 2nd Tier Level III Metrics

The researcher's findings for 2nd tier (8-14) metrics when working under Contractor - Lump Sum Contracts are illustrated in Table 4.91. There are dominated by the performance attribute of EPCM Agility.

- There are three (3) metrics (1.5, 3.2, and 5.3) that finished in the 2nd tier in both Q1 and Q3. There were Invoice Accuracy, Engineering Drawing Changes, and Engineering Drawing Changes;

- A mixture of metrics belonging to the performance attributes of EPCM Agility, Project Control and Procurement Reliability & Responsiveness dominated the 2nd tier of importance;

- Metric 7.2 (Equipment + Materials Spends) and metric 2.3 (Time to Respond to Procurement Inquiries) are also appreciated as being more important to contractors versus owners; with a 2nd tier finished in Q3, whereas they were ranked in the 3rd tier finished in Q1.

Table 4. 92
Level III Metrics 2nd Tier – Contractor / LS Contract

Perf. Attributes	Level II / III Metrics	Robustness	Interview: Category Ranking	Interview: Overall Ranking	Interview: Tiers 1-5	Contractor LS: 3 (Q3 Score)	Contractor LS: R (Q3 Ranking)	Contractor LS: T (Tier 1 to 5)
Project Control	7.2 Equipment + Materials Spends	86.6%	4	6	1	1.52	10	2
EPCM Agility	3.4 Engineering Reworks & NCR	83.9%	6	12	2	1.52	11	2
EPCM Agility	3.1 Engineering Changes Orders	83.9%	6	13	2	1.52	12	2
EPCM Agility	5.3 Engineering RFI	83.6%	9	20	2	1.48	8	2
EPCM Agility	3.2 Engineering Drawing Changes	83.3%	10	23	3	1.52	13	2
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	81.4%	1	30	4	1.52	14	2
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	80.2%	4	35	4	1.50	9	2

Dany Julien (2019)

4.4.3.3. 3rd Tier Level III Metrics

The researcher's findings for 3rd tier (15-21) metrics when working under Contractor - Lump Sum Contracts are illustrated in Table 4.92, with metrics belonging predominantly to Project Controls and EPCM Agility.

- Metric 6.2 (Earned and Burned Indicators) was the strongest ones in this 3rd tier. Understanding a contractor is responsible for bearing all the risks during a lump sum contract, this metric was expected to score higher for a contractor. Note that it is in the view of the researcher that metric 6.1 (Budget) and 6.2 (Earned and Burned Indicator) should have both scored in the 1st tier of importance, but not so, according to the participants in the survey.

Table 4. 93
Level III Metrics 3rd Tier – Contractor / LS Contract

Perf. Attributes	Level II / III Metrics	Robustness	Interview: Category Ranking	Interview: Overall Ranking	Interview: Tiers 1-5	Contractor LS: 3 (Q3 Score)	Contractor LS: R (Q3 Ranking)	Contractor LS: T (Tier 1 to 5)
Project Control	6.2 Earned and Burned Indicators	88.2%	1	1	1	1.57	15	3
Project Control	7.1 Labour (+ Management) Spends	86.9%	3	4	1	1.67	19	3
Project Control	7.3 Rework Spends	86.3%	5	7	1	1.62	16	3
EPCM Agility	5.5 Document Control	84.2%	5	11	2	1.62	17	3
EPCM Agility	5.4 Turnover & Commissioning	83.9%	6	14	2	1.67	20	3
EPCM Agility	4.1 Material Management at Site	83.8%	7	15	2	1.62	18	3
EPCM Agility	4.4 Inventory Management	83.0%	11	24	3	1.67	21	3

Dany Julien (2019)

4.4.4. 4th and 5th Tier Level III Metrics

The researcher's findings for 4th and 5th (22-37) metrics when working under Contractor - Lump Sum Contracts are illustrated in Table 4.93, with a mixture of metrics belonging to all performance attributes. Appendix K illustrates the results for Q3 - Survey.

- The metric 1.4 (Purchase Orders' Quality & Accuracy) top the 4th tier metrics, followed by metric 13.3 (Performance Analytics) and metric 2.1 (Time to complete Purchase Order Entries);

- Metrics pertaining to the performance attributes of Project Control and EPCM Agility are still dominant in the 4th and 5th tier.

Table 4. 94
Level III Metrics 4th and 4th Tier – Contractor / LS Contract

			Interview			Contractor LS		
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	3 (Q3 Score)	R (Q3 Ranking)	T (Tier 1 to 5)
Project Control	8.3 Warehouse / Laydown Spends	**83.6%**	6	16	2	**1.86**	26	4
Project Control	8.4 Inventory Carrying Costs Spends	**83.6%**	6	17	2	**2.00**	29	5
Project Control	8.1 Transportation Spends	**83.6%**	6	18	2	**2.05**	31	5
Project Control	7.4 IT Integration Spends	**83.6%**	6	19	2	**2.57**	37	5
EPCM Agility	4.3 Leased Equipment Used at Site	**83.6%**	9	21	3	**1.81**	25	4
Project Complexity	12.1 Contractor Base Complexity	**83.5%**	1	22	3	**2.29**	34	5
Project Complexity	12.2 Management Team / Owner Representatives	**82.9%**	2	25	3	**1.86**	27	4
Project Control	8.2 Customs Spends	**82.7%**	7	26	3	**2.33**	35	5
EPCM Agility	4.2 Transportation Management	**82.7%**	8	27	3	**2.00**	30	5
EPCM Agility	4.5 Bagging / Free Issue to Contractos / Expediting at Site	**82.1%**	12	28	3	**1.95**	28	4
EPCM Agility	5.6 IT Integration Issues & Solving	**81.8%**	13	29	3	**2.24**	33	5
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy	**81.0%**	2	31	4	**1.67**	22	4
Procur. Reliability & Responsiveness	2.1 Time to Complete Purchase Order Entries	**80.8%**	3	32	4	**1.76**	24	4
Employee Management	13.3 Performance Analytics	**80.4%**	1	33	4	**1.71**	23	4
Project Control	9.1 Suppliers Spends	**80.2%**	8	34	4	**2.19**	32	5
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	**80.1%**	14	36	4	**2.48**	36	5

Dany Julien (2019)

4.4.5. Question 4: Contractor / Time Materials Contract

When Contractors constructing mega-projects ($300M+) and operating under a "TIME MATERIALS / COSTS +% CONTRACT", which metrics would you consider measuring?

Time & Materials / Cost +% Contracts are used where scopes of work are uncertain, for instance, in terms of design drawing completion, and subsequently, cost of time labour and materials can easily become out of control. Contractors will opt for this contract when project drawings and the scope of work are not completed before the projects are set to start. In this type of contract, contractors have an advantage over owners in terms of cost and risk bearing during a project. In this case, the contractors may have some leniencies in completing works as they are being paid under time and materials, due to undefined scope of work and drawings.

4.4.5.1. 1st Tier Level III Metrics

The researcher's findings for 1st tier (1-7) metrics when working under Contractor - Time Materials / Cost +% Contract are illustrated in Table 4.94. The metrics in the 1st tier respect the contractual thinking of a Time Materials / Cost +% Contract.

Table 4. 95
Level III Metrics 1st Tier – Contractor / T&M Contract

Perf. Attributes	Level II / III Metrics	Robustness	Interview Category Ranking	Interview Overall Ranking	Interview Tiers 1-5	Contractor T&M 4 (Q4 Score)	Contractor T&M R (Q4 Ranking)	Contractor T&M T (Tier 1 to 5)
Project Control	6.2 Earned and Burned Indicators	**88.2%**	1	1	1	**1.45**	4	1
EPCM Agility	5.8 Health, Safety & Environment	**88.1%**	1	2	1	**1.14**	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	**87.5%**	2	3	1	**1.32**	2	1
Project Control	7.1 Labour (+ Management) Spends	**86.9%**	3	4	1	**1.41**	3	1
EPCM Agility	5.2 Schedule Changes	**86.8%**	2	5	1	**1.50**	5	1
Project Control	7.2 Equipment + Materials Spends	**86.6%**	4	6	1	**1.59**	6	1
Project Control	7.3 Rework Spends	**86.3%**	5	7	1	**1.64**	7	1

Dany Julien (2019)

- The metrics belonging to the performance attributes of Project Control and EPCM Agility are dominating the 1st tier, when working under the Contractor - Time Materials / Cost +% Contract;

- All seven (7) metrics in the Q3 survey were also ranked in the 1st tier of robustness during the interviews;

- Except for metric 7.3 (Rework Spends), all other metrics in Q4 are identical to the metrics in Q2; This indicate that either owners or contractors, these metrics are important under Time Materials / Cost +% Contract.

4.4.5.2. 2nd Tier Level III Metrics

The researcher's findings for 2nd tier (8-14) metrics when working under Contractor - Time Materials / Cost + % Contract are illustrated in Table 4.95, with predominantly metrics belonging to the performance attribute of EPCM Agility.

- Metrics belonging to the performance attributes of EPCM Agility dominate this tier, with six (6) metrics out of seven (7);

- Metric 1.5 (Invoice Accuracy) is the other performance attribute (Procurement Reliability & Responsiveness) in this 2nd tier when working under Contractor - Time Materials / Cost + % Contract. It should also be noted this metric went from a ranking of thirty-five (35), in terms of robustness during the interviews, to a strong 11th position, when working under a Contractor - Time Materials / Cost +% Contract. This is an evidence that being accurate when invoicing indicates the importance of this metric during such contract type.

Table 4. 96
Level III Metrics 2nd Tier – Contractor / T&M Contract

		Interview				Contractor T&M (Q4 Score / Q4 Ranking / Tier 1 to 5)		
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	4	R	T
EPCM Agility	5.1 Schedule (FIWP) Development	**85.7%**	3	8	1	**1.64**	8	2
EPCM Agility	5.3 Construction Site Performance	**85.7%**	3	9	1	**1.64**	9	2
EPCM Agility	5.5 Document Control	**84.2%**	5	11	2	**1.77**	14	2
EPCM Agility	3.4 Engineering Reworks & NCR	**83.9%**	6	12	2	**1.64**	10	2
EPCM Agility	3.1 Engineering Changes Orders	**83.9%**	6	13	2	**1.68**	12	2
EPCM Agility	3.2 Engineering Drawing Changes	**83.3%**	10	23	3	**1.68**	13	2
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	**80.2%**	4	35	4	**1.64**	11	2

Dany Julien (2019)

4.4.5.3. 3rd Tier Level III Metrics

The researcher's findings for 3rd tier (15-21) metrics when working under Contractor - Time Materials / Cost +% Contract are illustrated in Table 4.96, with a mixture of metrics belonging to several performance attributes.

- Metrics belonging to the performance attribute of EPCM Agility dominate this 3rd tier with four (4) out of seven (7) metrics;

- The two (2) metrics belonging to the performance attributes of Procurement Reliability & Responsiveness (1.1 and 1.4) demonstrate some importance of delivering materials at site on time, so to avoid cost increase. However, these procurement metrics are only seen in the 3rd tier;

- The metric 13.3 (Performance Analytics) is the first metrics belonging to the performance attributes of Workers Management. It is seen ranked in the 3rd tier only.

Table 4. 97
Level III Metrics 3rd Tier – Contractor / T&M Contract

			Interview			Contractor T&M		
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	4 (Q4 Score)	R (Q4 Ranking)	T (Tier 1 to 5)
EPCM Agility	5.7 Contract / Labour Issues & Solving	**84.8%**	4	10	1	**1.86**	17	3
EPCM Agility	5.4 Turnover & Commissioning	**83.9%**	6	14	2	**1.86**	18	3
EPCM Agility	4.1 Material Management at Site	**83.8%**	7	15	2	**1.77**	15	3
EPCM Agility	5.3 Engineering RFI	**83.6%**	9	20	2	**1.91**	21	3
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy	**81.0%**	2	31	4	**1.77**	16	3
Employee Management	13.3 Performance Analytics	**80.4%**	1	33	4	**1.86**	19	3
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	**79.9%**	6	37	4	**1.86**	20	3

Dany Julien (2019)

4.4.5.4. 4th and 5th Tier Level III Metrics

The researcher' findings for the 4th and 5th (22-37) metrics when working under Contractor - Time Materials / Cost +% Contract are illustrated in Table 4.97, with a mixture of metrics belonging to all performance attributes. Appendix K illustrates the results for Q4 – Survey.

- The metrics in this 4th and 5th tier when working under Contractor - Time Materials / Cost +% Contract are a mix of level of robustness metrics which scored in 2nd, 3rd and 4th tier during the interviews. This level of robustness is also important for future research, as to be tested by other participants for their importance.

Table 4. 98
Level III Metrics 4th and 5th Tier – Contractor / T&M Contract

			Interview			Contractor T&M		
						Q4 Score	Q4 Ranking	Tier 1 to 5
Perf. Attributes	Level II / III Metrics	Robustness	Category Ranking	Overall Ranking	Tiers 1-5	4	R	T
Project Control	8.3 Warehouse / Laydown Spends	83.6%	6	16	2	2.14	28	4
Project Control	8.4 Inventory Carrying Costs Spends	83.6%	6	17	2	2.18	29	5
Project Control	8.1 Transportation Spends	83.6%	6	18	2	2.09	27	4
Project Control	7.4 IT Integration Spends	83.6%	6	19	2	2.50	36	5
EPCM Agility	4.3 Leased Equipment Used at Site	83.6%	9	21	3	2.00	25	4
Project Complexity	12.1 Contractor Base Complexity	83.5%	1	22	3	2.18	30	5
EPCM Agility	4.4 Inventory Management	83.0%	11	24	3	1.95	23	4
Project Complexity	12.2 Management Team / Owner Representatives	82.9%	2	25	3	1.91	22	4
Project Control	8.2 Customs Spends	82.7%	7	26	3	2.41	34	5
EPCM Agility	4.2 Transportation Management	82.7%	8	27	3	2.18	31	5
EPCM Agility	4.5 Bagging / Free Issue to Contractos / Expediting at Site	82.1%	12	28	3	2.27	32	5
EPCM Agility	5.6 IT Integration Issues & Solving	81.8%	13	29	3	2.36	33	5
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	81.4%	1	30	4	1.95	24	4
Procur. Reliability & Responsiveness	2.1 Time to Complete Purchase Order Entries	80.8%	3	32	4	2.05	26	4
Project Control	9.1 Suppliers Spends	80.2%	8	34	4	2.50	37	5
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	80.1%	14	36	4	2.41	35	5

Dany Julien (2019)

4.4.6. Conclusion – Final Artifact (CPPM)

The premises on selecting the metrics for the final artifact were arbitrarily made by researcher with the following explanations. At first, the SCOR Model, included 250+ Level III metrics, which are used primarily to measure supply chain performances in a manufacturing environment. Thus, at the onset of designing the artifact, the researcher enriched the SCOR Model to 366 Level III metrics with a reflection to cover over all mega-project phases. Then, through series of semi-structured interviews, the enriched model was reduced to 305 Level III metrics, which represented the Modified SCOR Model. Finally, after analysing the survey, the Modified SCOR Model was further minimised through a series of four (4) questions related to construction contracts. This last step of minimisation resulted into the thesis' artifact named Construction Performance & Productivity Model (CPPM). The resultant of this model (CPPM) is in line with the research's objectives, such as; (1) a construction model that is friendly to use by construction stakeholders; (2) provide performance attributes and metrics, which are useful to construction specialists, and (3) by providing real-time measurement at construction site, which will help forecasting projects' costs and delivery scheduled throughout the projects' phases; (4) filling the literature gap in construction project management, by offering a model that covers all phases and activities of construction mega-projects; and (5) the implementation of a supply chain approach as the basics framework for the model proposed.

Overall, the researcher on one hand, wanted to meet these research objectives stated above and on the other hand, reduced the large number of metrics to make the artifact user-friendly. The overall ranking of the Level II/III metrics for the artifact CPPM is illustrated in Table 4.98:

a) 1st tier (ranking of 1 to 7): Level II/III metrics 1.5, 3.1 and 4.4 performed better during the survey;

b) 2nd tier (ranking between 8 and 14): Level II/III metrics 6.2, 7.1, and 7.2 performed better during the interviews, whereas Level II/III metrics 1.1 and 3.2 performed better during the survey;

c) 3rd tier (ranking between 15 to 21): Level II/III metrics 4.1, 5.3, 5.5, 5.7 and 7.3 performed better during the interviews, whereas Level II/III metrics 2.3 and 13.3 performed better during the survey;

d) 4th tier (ranking between 22 and 28): Level II/III metrics 4.3, 4.4, 4.5, 8.3 and 12.2 performed better during the interviews; and

e) the 5th tier (ranking between 29 and 37): All the Level II/III metrics performed better during the interviews.

Table 4. 99
Top 37 Level II/III Metrics

			Modified SCOR Model			CPPM		
			Semi-Structured Interviews			Survey		
Performance Attributes	Level II / III Metrics		Robustness	Overall Ranking	Tiers 1-5	Robustness	Overall Ranking	Tiers 1-5
EPCM Agility	5.8	Health, Safety & Environment	88,1%	2	1	1,20	1	1
Project Control	6.1	Budget (Acutal vs. EAC)	87,5%	3	1	1,42	3	1
EPCM Agility	5.2	Schedule Changes	86,8%	5	1	1,39	2	1
EPCM Agility	5.1	Schedule (FIWP) Development	85,7%	8	1	1,52	5	1
EPCM Agility	3.4	Engineering Reworks & NCR	83,9%	12	2	1,48	4	1
EPCM Agility	3.1	Engineering Changes Orders	83,9%	13	2	1,55	6	1
Procur. Reliability & Responsiveness	1.5	Invoices' Accuracy	80,2%	35	4	1,58	7	1

			Modified SCOR Model			CPPM		
			Semi-Structured Interviews			Survey		
Performance Attributes	Level II / III Metrics		Robustness	Overall Ranking	Tiers 1-5	Robustness	Overall Ranking	Tiers 1-5
Project Control	6.2	Earned and Burned Indicators	88,2%	1	1	1,56	8	2
Project Control	7.1	Labour (+ Management) Spends	86,9%	4	1	1,61	11	2
Project Control	7.2	Equipment + Materials Spends	86,6%	6	1	1,62	12	2
EPCM Agility	5.4	Turnover & Commissioning	83,9%	14	2	1,68	13	2
EPCM Agility	5.3	Engineering RFI	83,6%	20	2	1,68	14	2
EPCM Agility	3.2	Engineering Drawing Changes	83,3%	23	3	1,60	10	2
Procur. Reliability & Responsiveness	1.1	Delivery Performance Against Requested Date	79,9%	37	4	1,58	9	2

		Modified SCOR Model			CPPM		
		Semi-Structured Interviews			Survey		
Performance Attributes	Level II / III Metrics	Robustness	Overall Ranking	Tiers 1-5	Robustness	Overall Ranking	Tiers 1-5
Project Control	7.3 Rework Spends	86,3%	7	1	1,72	17	3
EPCM Agility	5.3 Construction Site Performance	85,7%	9	1	1,71	16	3
EPCM Agility	5.7 Contract / Labour Issues & Solving	84,8%	10	1	1,75	18	3
EPCM Agility	5.5 Document Control	84,2%	11	2	1,76	19	3
EPCM Agility	4.1 Material Management at Site	83,8%	15	2	1,70	15	3
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	81,4%	30	4	1,79	20	3
Employee Management	13.3 Performance Analytics	80,4%	33	4	1,81	21	3

		Modified SCOR Model			CPPM		
		Semi-Structured Interviews			Survey		
Performance Attributes	Level II / III Metrics	Robustness	Overall Ranking	Tiers 1-5	Robustness	Overall Ranking	Tiers 1-5
Project Control	8.3 Warehouse / Laydown Spends	83,6%	16	2	2,08	28	4
EPCM Agility	4.3 Leased Equipment Used at Site	83,6%	21	3	2,00	26	4
EPCM Agility	4.4 Inventory Management	83,0%	24	3	1,82	22	4
Project Complexity	12.2 Management Team / Owner Representatives	82,9%	25	3	1,86	24	4
EPCM Agility	4.5 Bagging / Free Issue to Contractos / Expediting at S	82,1%	28	3	2,06	27	4
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy	81,0%	31	4	1,84	23	4
Procur. Reliability & Responsiveness	2.1 Time to Complete Purchase Order Entries	80,8%	32	4	1,93	25	4

		Modified SCOR Model			CPPM		
		Semi-Structured Interviews			Survey		
Performance Attributes	Level II / III Metrics	Robustness	Overall Ranking	Tiers 1-5	Robustness	Overall Ranking	Tiers 1-5
Project Control	8.4 Inventory Carrying Costs Spends	83,6%	17	2	2,11	30	5
Project Control	8.1 Transportation Spends	83,6%	18	2	2,09	29	5
Project Control	7.4 IT Integration Spends	83,6%	19	2	2,51	37	5
Project Complexity	12.1 Contractor Base Complexity	83,5%	22	3	2,34	32	5
Project Control	8.2 Customs Spends	82,7%	26	3	2,38	35	5
EPCM Agility	4.2 Transportation Management	82,7%	27	3	2,14	31	5
EPCM Agility	5.6 IT Integration Issues & Solving	81,8%	29	3	2,34	33	5
Project Control	9.1 Suppliers Spends	80,2%	34	4	2,37	34	5
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	80,1%	36	4	2,43	36	5

Dany Julien (2019)

In summary, the Construction Performance & Productivity Model provides several tiers, which represents enriched performance attributes and Level I, II, II metrics representing all phases of mega-projects. Table 4.99 reflects all five (5) tiers of the CPPM.

Table 4. 100
CPPM Performance Attributes & Metrics

	Semi-Structured Interviews		Survey	Artifact - CPPM				
	SCOR Model	Enriched SCOR Model	Modified SCOR Model	CPPM Tier 1	CPPM Tier 2	CPPM Tier 3	CPPM Tier 4	CPPM Tier 5
Performance Attributes (Quantitative)	5	7	5	3	3	5	5	5
Performance Attributes (Qualitative)	2	0	1	0	0	0	1	1
Level I Metrics	10	13	11	4	5	8	10	11
Level II Metrics	27	49	38	7	14	21	28	37
Level III Metrics	250	366	305	86	130	188	223	305

Dany Julien (2019)

Understanding this artifact has several tiers of utilities and uses a supply chain operative framework, the researcher investigated if there were certain dominance of performance attributes and metrics belonging more to one category. Tables 4.100, 4.101 and 4.102 display the levels of dominance.

The 1st tier of the Construction Performance & Productivity Model demonstrates three (3) important performance attributes, four (4) Level I metrics, seven (7) Level II metrics and a total of 86 Level III metrics. The 1st tier of the Construction Performance & Productivity Model is displayed in Table 4.100, with a strong performance by the ECPM Agility across the model. Project Control is also an important performance attribute for the CPPM's 1st tier. 73% of the Level III metrics belong to EPCM Agility.

Table 4. 101
Final 1st tier: Level of Dominance

Artifact: Construction Performance & Productivity Model Artifact: 1st Tier						
1st Tier: 3	1st Tier: 4		1st Tier: 7		1st Tier: 86	
Performance Attributes	**Level I Metrics**	**% (I)**	**Level II Metrics**	**% (II)**	**Level III Metrics**	**% (II)**
I. Procurement Reliability	1. Delivery Performance	20%	1.1. Delivery Performance Against Owner's Requested Date	14%	1.1: 16 metrics Total: 16 metrics	19%
III. EPCM Agility	3. "E" Engineering 5. "CM" Construction Management	40%	3.1 Engineering Change Orders 3.4 Engineering Reworks & NCR 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.8 Health, Safety & Environment	71%	3.1: 6 metrics 3.2: 22 metrics 5.1: 12 metrics 5.2: 5 metrics 5.8: 17 metrics Total: 62 metrics	73%
IV. Project Controls	6. Budget & Planning	40%	6.1 Budget (Actual vs. EAC)	14%	6.1 8 metrics Total = 8 metrics	9%

Dany Julien (2019)

The 2nd tier of the Construction Performance & Productivity Model demonstrates three (3) important performance attributes, five (5) Level I metrics, fourteen (14) Level II metrics and a total of 130 Level III metrics. The 2nd tier of the Construction Performance & Productivity Model is displayed in Table 4.101, with even a stronger performance by the ECPM Agility than in the 1st tier option. The 2nd tier of the CPPM also add a fifth Level I metric (LEM Spends) and 65% of the Level III metrics belong to EPCM Agility.

Table 4. 102

Final 1st + 2nd Tier: Level of Dominance

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier						
2nd Tier: 3	2nd Tier: 5		2nd Tier: 14		2nd Tier: 130	
Performance Attributes	Level I Metrics	% (I)	Level II Metrics	% (II)	Level III Metrics	% (III)
I. Procurement Reliability	1. Delivery Performance	20%	1.1. Delivery Performance Against Owner's Requested Date 1.5 Invoices' Accuracy	14%	1.1: 16 metrics 1.5: 10 metrics Total: 26 metrics	20%
III. EPCM Agility	3. "E" Engineering 5. "CM" Construction Management	40%	3.1 Engineering Changes Orders 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks & NCR 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.4 Turnover & Commissioning 5.8 Health, Safety & Environment	50%	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 22 metrics 5.1: 12 metrics 5.2: 5 metrics 5.4: 9 metrics 5.8: 17 metrics Total: 84 metrics	65%
IV. Project Controls	6. Budget & Planning 7. LEM Spends	40%	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends	36%	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics Total = 20 metrics	15%

The 3rd tier of the Construction Performance & Productivity Model demonstrates three (3) important performance attributes, five (5) Level I metrics, fourteen (14) Level II metrics and a total of 130 Level III metrics. The 3rd tier of the Construction Performance & Productivity Model is displayed in Table 4.102. EPCM demonstrates its dominance with 72% of the Level III metrics belong to this performance attributes. The 3rd tier also add two (2) performance attributes, three (3) Level I metrics and six (6) Level II metrics. Project Controls and Performance Reliability demonstrate 13% and 14% Level III metrics respectively.

Table 4. 103
Final 1st + 2nd + 3rd Tier: Level of Dominance

Construction Performance & Productivity Model Artifact: 1st, 2nd, 3rd Tier						
3rd Tier:5	3rd Tier: 8		3rd Tier: 21		3rd Tier: 188	
Performance Attributes	Level I Metrics	% (I)	Level II Metrics	% (II)	Level III Metrics	% (III)
I. Procurement Reliability	1. Delivery Performance	13%	1.1. Delivery Performance Against Owner's Requested Date 1.5 Invoices' Accuracy	10%	1.1: 16 metrics 1.5: 10 metrics Total: 26 metrics	14%
II. Procurement Responsiveness	2. Purchase Order Fulfillment Cycle Time	13%	2.3 Inquiry Time - Procurement	5%	2.3: 2 metrics Total: 2 metrics	1%
III. EPCM Agility	3. "E" Engineering 4. "P" Procurement 5. "CM" Construction Management	38%	3.1 Engineering Changes Orders 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks & NCR 4.1 Material Management 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning 5.5 Document Control 5.7 Contract & Labour 5.8 Health, Safety & Environment	57%	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 22 metrics 4.1: 19 metrics 5.1: 12 metrics 5.2: 5 metrics 5.3: 23 metrics 5.4: 9 metrics 5.5: 2 metrics 5.7: 8 metrics 5.8: 17 metrics Total: 136 metrics	72%
IV. Project Controls	6. Budget & Planning 7. LEM Spends	25%	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends 7.3 Rework Spends	24%	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics 7.3 4 metrics Total = 24 metrics	13%
VII. Project Integration	13. Performance Analytics	13%	13.3 Performance Analytics	5%	N/A	N/A

The level of dominance for the 4th and 5th tier is not presented in this section, as together, they represent all level of performance attributes and Level I, II and III metrics.

The last step into selecting the most optimal metrics for the artifact was based on meeting the last research's objective and its research question. The artifact CPPM must adapt to several types of construction contracts, such as time & materials (cost plus) and lump sum contracts, for owners and contractors.

4.4.6.1. Final Artifact: 1st Tier – All Four Contracts

When comparing all four (4) types of contracts presented to the participants, a total of thirteen (13) Level II / III metrics were retained as part of the 1st Tier. The 1st Tier Level II / III metrics are illustrated in Table 4.103. This research observed that only wo (2) metrics were inclusive to all four (4) types of contracts in this 1st Tier.

Table 4. 104
Final 1st Tier Level II / III Metrics – All Four Contracts

		Owner LS			Owner T&M			Contractor LS			Contractor T&M		
		Q1 - Score	Q1 Ranking	Tier 1 to 5	Q2 Score	Q2 Ranking	Tier 1 to 5	Q3 Score	Q3 Ranking	Tier 1 to 5	Q4 Score	Q4 Ranking	Tier 1 to 5
Perf. Attributes	**Level II / III Metrics**	1	R	T	2	R	T	3	R	T	4	R	T
Project Control	6.2 Earned and Burned Indicators				**1.18**	1	1				**1.45**	4	1
EPCM Agility	5.8 Health, Safety & Environment	**1.22**	1	1	**1.27**	2	1	**1.19**	1	1	**1.14**	1	1
Project Control	6.1 Budget (Acutal vs. EAC)				**1.32**	3	1	**1.38**	3	1	**1.32**	2	1
Project Control	7.1 Labour (+ Management) Spends				**1.36**	5	1				**1.41**	3	1
EPCM Agility	5.2 Schedule Changes	**1.32**	3	1	**1.32**	4	1	**1.43**	5	1	**1.50**	5	1
Project Control	7.2 Equipment + Materials Spends				**1.36**	6	1				**1.59**	6	1
EPCM Agility	5.1 Schedule (FIWP) Development	**1.50**	7	1				**1.38**	4	1			
EPCM Agility	5.3 Construction Site Performance							**1.43**	6	1			
EPCM Agility	5.7 Contract / Labour Issues & Solving							**1.33**	2	1			
EPCM Agility	3.4 Engineering Reworks & NCR	**1.30**	2	1	**1.45**	7	1						
EPCM Agility	3.1 Engineering Changes Orders	**1.39**	5	1									
EPCM Agility	5.4 Turnover & Commissioning	**1.48**	6	1									
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	**1.35**	4	1				**1.43**	7	1			

Dany Julien (2019)

- Level II/III metrics 5.8 (Health, Safety & Environment) and 5.2 (Schedule Changes) were inclusive to all types of contracts. This result confirms that health, safety and the environment are first and far most important metrics to all the construction stakeholders, during mega-projects;

- The Level II/III metric 5.2 Schedule Changes have profound effect of projects' costs and delays, no matter what forms of contracts owners and contractors are operating under.

- The performance attribute of Project Controls (6.1) was sought by three (3) out of four (4) contracts;

- Procurement (1.1), EPCM – engineering (3.4), EPCM – construction (5.1), Project Controls (6.2, 7.1, 7.2) was sought by (2) types of contracts;

- The performance attributes EPCM – engineering (3.1), EPCM – construction (5.3, 5.4) and Project Controls (5.7) were sought by only one (1) type of contract;

It is therefore conclusive that Level II/III metrics 5.8 (Health, Safety & Environment) and 5.2 (Schedule Changes) were the most important metrics in the 1st Tier – All Four Contracts, and must be part of the final artifact (CPPM).

4.4.6.2. Final Artifact: 1st Tier - Lump Sum Contracts

When comparing Lump Sum contracts between owners and contractors, we noted in Table 4.104, the following results amongst the 1st Tier Level II / III metrics:

Table 4. 105
Final 1st Tier Level II / III: Lump Sum Contacts

			Owner LS			Contractor LS		
			Q1 - Score	Q1 Ranking	Tier 1to5	Q3 Score	Q3 Ranking	Tier 1to5
Perf. Attributes	**Level II / III Metrics**		1	R	T	3	R	T
EPCM Agility	5.8	Health, Safety & Environment	**1,22**	1	1	**1,19**	1	1
Project Control	6.1	Budget (Acutal vs. EAC)				**1,38**	3	1
EPCM Agility	5.2	Schedule Changes	**1,32**	3	1	**1,43**	5	1
EPCM Agility	5.1	Schedule (FIWP) Development	**1,50**	7	1	**1,38**	4	1
EPCM Agility	5.3	Construction Site Performance				**1,43**	6	1
EPCM Agility	5.7	Contract / Labour Issues & Solving				**1,33**	2	1
EPCM Agility	3.4	Engineering Reworks & NCR	**1,30**	2	1			
EPCM Agility	3.1	Engineering Changes Orders	**1,39**	5	1			
EPCM Agility	5.4	Turnover & Commissioning	**1,48**	6	1			
Procur. Reliability & Responsiveness	1.1	Delivery Performance Against Requested Date	**1,35**	4	1	**1,43**	7	1

Dany Julien (2019)

- Metric 1.1 (Delivery Performance against Requested Date), 5.1 (Schedule FIWP Development), 5.2 (Schedule Changes), 5.8 (Health, Safety & Environment) were four (4) metrics that both ownerships and contractors believe essentials during any types of Lump Sum contracts;

- When under a Lump Sum contract, the consideration of having materials and equipment on time, working in a safe and secure environment, supported by strong planning procedures, so crews and management can coordinate their efforts in installing field materials on time, were essential KPIs to have in order to complete the project on time and on budget;

- The performance attributes that had only one (1) type of contract when considering being an owner, were EPCM Agility – engineering (3.1, 3.4), EPCM – construction (5.4);

- The performance attributes that had only one (1) type of contract when considering being a contactor, were EPCM Agility – construction (5.3 and 5.7) and Project Controls (6.1);

It is therefore conclusive that four (4) metrics (1.1, 5.1, 5.2, and 5.8) are needed to be included in the model's artifact.

4.4.6.3. Final Artifact: 1st Tier - Time & Materials Contracts

The 1st Tier Level II / III metrics for Time & Materials contracts are mostly homogenous between owner and contractors' interests. Both stakeholders consider vey similar metrics (5.2, 5.8, 6.1, 6.2, 7.1 and 7.2) as demonstrated in the results in Table 4.105:

Table 4. 106
Final 1st Tier Level II / III: Time Materials Contracts

		Owner T&M			Contractor T&M		
		Q2 Score	Q2 Ranking	Tier 1 to 5	Q4 Score	Q4 Ranking	Tier 1 to 5
Perf. Attributes	Level II / III Metrics	2	R	T	4	R	T
Project Control	6.2 Earned and Burned Indicators	1,18	1	1	1,45	4	1
EPCM Agility	5.8 Health, Safety & Environment	1,27	2	1	1,14	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	1,32	3	1	1,32	2	1
Project Control	7.1 Labour (+ Management) Spends	1,36	5	1	1,41	3	1
EPCM Agility	5.2 Schedule Changes	1,32	4	1	1,50	5	1
Project Control	7.2 Equipment + Materials Spends	1,36	6	1	1,59	6	1
EPCM Agility	3.4 Engineering Reworks & NCR	1,45	7	1			

Dany Julien (2019)

- Metric 5.2 (Schedule Change) and 5.8 (Health, Safety & Environment) are two (2) metrics that both owners and contractors see as essential in controlling cost and time through monitoring schedule changes, working safely and in security;

- Metric 6.1 Budget (Actual & EAC) and 6.2 (Earned and Burned Indicators) are two KPIs that are used world-wise in project management. Understanding that controlling labour (time) costs and equipment (materials) costs are essential in completing a project on time and on budget. The importance of these two (2) metrics is correlating with today's construction reality;

- Metric 7.1 (Labour & Management) and 7.2 (Equipment & Materials Spends) are most often known under the term LEM in construction. The importance of LEM metrics during mega-projects are confirmed in this survey, when operating under a Time & Materials agreement;

It is therefore conclusive that six (6) metrics (5.2, 5.8, 6.1, 6.2, 7.1, and 7.2) are needed to be included in the model's artifact. Overall, in terms of the 1st Tier Level II/III metrics, the artifact (CPPM) shall be represented with the metrics stated in Table106.

Table 4. 107
1st Tier Level II / III Metrics – CPPM

	1st Tier - CPPM		
	All Forms of Contract	Lump Sum Contracts	Time & Materials Contract
Procurement Reliability		1.1	
EPCM Agility	5.2, 5.8	5.1, 5.2, 5.8	5.2, 5.8
Project Control			6.1, 6.2, 7.1, 7.2

Dany Julien (2019)

4.4.6.4. Final Artifact: 2nd Tier – All Four Contracts

When considering all four (4) types of contracts presented to the participants, a total of twenty-one (21) Level II / III metrics were retained as part of the top 2nd Tier during the survey. These 2nd Tier Level II / III metrics are illustrated in Table 4.107 and marked the top 14 metrics in each category.

Table 4. 108
2nd Tier Level II / III Metrics – All Four Contracts

		Q1 - Score	Q1 Ranking	Tier 1 to 5	Q2 Score	Q2 Ranking	Tier 1 to 5	Q3 Score	Q3 Ranking	Tier 1 to 5	Q4 Score	Q4 Ranking	Tier 1 to 5
		Owner LS			Owner T&M			Contractor LS			Contractor T&M		
Perf. Attributes	**Level II / III Metrics**	1	R	T	2	R	T	3	R	T	4	R	T
Project Control	6.2 Earned and Burned Indicators				1,18	1	1				1,45	4	1
EPCM Agility	5.8 Health, Safety & Environment	1,22	1	1	1,27	2	1	1,19	1	1	1,14	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	1,65	10	2	1,32	3	1	1,38	3	1	1,32	2	1
Project Control	7.1 Labour (+ Management) Spends				1,36	5	1				1,41	3	1
EPCM Agility	5.2 Schedule Changes	1,32	3	1	1,32	4	1	1,43	5	1	1,50	5	1
Project Control	7.2 Equipment + Materials Spends				1,36	6	1	1,52	10	2	1,59	6	1
Project Control	7.3 Rework Spends				1,50	9	2				1,64	7	1
EPCM Agility	5.1 Schedule (FIWP) Development	1,50	7	1	1,55	10	2	1,38	4	1	1,64	8	2
EPCM Agility	5.3 Construction Site Performance							1,43	6	1	1,64	9	2
EPCM Agility	5.7 Contract / Labour Issues & Solving							1,33	2	1			
EPCM Agility	5.5 Document Control	1,86	14	2							1,77	14	2
EPCM Agility	3.4 Engineering Reworks & NCR	1,30	2	1	1,45	7	1	1,52	11	2	1,64	10	2
EPCM Agility	3.1 Engineering Changes Orders	1,39	5	1	1,59	12	2	1,52	12	2			
EPCM Agility	5.4 Turnover & Commissioning	1,48	6	1									
EPCM Agility	4.1 Material Management at Site	1,74	11	2	1,68	14	2						
EPCM Agility	3.3 Engineering RFI	1,78	12	2	1,55	11	2	1,48	8	2			
EPCM Agility	3.2 Engineering Drawing Changes	1,52	8	2				1,52	13	2	1,68	13	2
EPCM Agility	4.4 Inventory Management				1,59	13	2						
Project Integration	13.3 Performance Analytics	1,83	13	2									
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	1,61	9	2	1,45	8	2				1,64	11	2
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	1,35	4	1				1,43	7	1			

Dany Julien (2019)

Amongst these 2nd Tier ranking, there were five (5) metrics that were observed as important to both owners and contractors, lump sum and time & material contracts.

There were the metrics belonging to the performance attributes of EPCM Agility, including engineering (3.4) and construction management (5.1, 5.2, 5.8) as well as Project Controls (6.1). The overall performance for the 2nd Tier Level II/III metrics were as followed:

- The performance attributes that had metrics in all form of categories were the EPCM Agility – engineering (3.4 -Engineering Reworks & NCR); EPCM Agility – construction (5.1 - Health, Safety & Environment, 5.2 - Schedule Changes, 5.8 - Health, Safety & Environment) and Project Controls (6.1- Budget – Actual vs. EAC);

- The performance attributes that had three (3) types of contracts were Procurement (1.5), EPCM - engineering (3.1, 3.2, 3.3) and Project Controls (7.2);

- The performance attributes that had two (2) types of contracts were also Procurement (1.1), EPCM – procurement (4,1), EPCM – construction (5,3, 5.5), and Project Controls (6.2, 7.1 and 7.3);

- The performance attributes that represented only one (1) type of contracts were EPCM - procurement (4.4), EPCM – construction (5.4, 5.7) and Project Integration 13.3.

It is therefore conclusive that five (5) metrics (3.4, 5.1, 5.2, 5.8, 6.1) are needed to be included in the model's artifact, when considering 2nd Tier.

4.4.6.5. Final Artifact: 2nd Tier - Lump Sum Contracts

The 2nd Tier Level II / III metrics for Lump Sum contracts are illustrated in Table 4.108. When considering Lump Sum contracts, we note the following results amongst the 2nd Tier Level II / III metrics:

Table 4. 109
Final 2nd Tier Level II / III: Lump Sum Contacts

Perf. Attributes	Level II / III Metrics	Q1 - Score	Q1 Ranking	Tier 1 to 5	Q3 Score	Q3 Ranking	Tier 1 to 5
		Owner LS			Contractor LS		
		1	R	T	3	R	T
EPCM Agility	5.8 Health, Safety & Environment	1,22	1	1	1,19	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	1,65	10	2	1,38	3	1
EPCM Agility	5.2 Schedule Changes	1,32	3	1	1,43	5	1
Project Control	7.2 Equipment + Materials Spends				1,52	10	2
EPCM Agility	5.1 Schedule (FIWP) Development	1,50	7	1	1,38	4	1
EPCM Agility	5.3 Construction Site Performance				1,43	6	1
EPCM Agility	5.7 Contract / Labour Issues & Solving				1,33	2	1
EPCM Agility	5.5 Document Control	1,86	14	2			
EPCM Agility	3.4 Engineering Reworks & NCR	1,30	2	1	1,52	11	2
EPCM Agility	3.1 Engineering Changes Orders	1,39	5	1	1,52	12	2
EPCM Agility	5.4 Turnover & Commissioning	1,48	6	1			
EPCM Agility	4.1 Material Management at Site	1,74	11	2			
EPCM Agility	3.3 Engineering RFI	1,78	12	2	1,48	8	2
EPCM Agility	3.2 Engineering Drawing Changes	1,52	8	2	1,52	13	2
Project Integration	13.3 Performance Analytics	1,83	13	2			
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	1,61	9	2			
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	1,35	4	1	1,43	7	1

Dany Julien (2019)

- The performance attributes that were ranked 2nd Tier Level II / III metrics during the Lump Sum contracts, that were important to both owners and contractors were Procurement (1.1), ECPM Agility - engineering (3.1, 3.2, 3.3, 3.4), EPCM – construction (5.1, 5.2, 5.8) and Project Controls (6.1);

- Metric 1.1 (Delivery Performance against Requested Date) is observed as important, considering materials and equipment arriving on time at site is essential to a project success;

- Metric 3.1 (Engineering Change Orders), 3.2 (Engineering Drawing Changes), 3.3 (Engineering RFI) and 3.4 (Engineering Reworks & NCR) are observed as important. These engineering metrics value the dynamic environment of project engineering and the constant changing requests that engineering faces in a project;

- Metric 5.1 (Schedule FIWP Development), 5.2 (Schedule Changes) are also observed as important. These construction metrics emphasise the importance of having strong planning program in order to complete the project on time and on budget;

- Metric 5.8 (Health, Safety & Environment) is once again one of the most important metrics in a project, where working at a safe and secure site is very important to a project's success;

- Metric 6.1 (Budget – Actual vs. EAC) are observed as important. Controlling a budget during a mega-project is an important activity even under a Lump Sum contract;

It is further concluded, when considering the 2nd Tier level, that these metrics enumerated above (1.1, 3.1 to 3.4, 5.1, 5.2, 5.8, 6.1) are to be included in model's artifact.

4.4.6.6. Final Artifact: 2nd Tier - Time & Materials Contracts

The 2nd Tier Level III metrics for Time & Materials contracts are like the 1st Tier result in a previous section, that is being mostly homogenous between owners and contractors' interests. There were ten (10) metrics that were important to both owners and contractors. For instance, the performance attributes that were ranked within the 2nd Tier Level II / III metrics when operating under Time Materials contracts, and important to both owners and contractors, were 1.5, 3.4, 5.1, 5.2, 5.8, 6.1, 6.2, 7.1, 7.2, 7.3. The 2nd Tier Level II / III metrics for Time & Materials contracts are illustrated in Table 4.109.

Table 4. 110
Final 1st & 2nd Tier Level II / III: T&M Contacts

		Owner T&M			Contractor T&M		
		Q2 Score	Q2 Ranking	Tier 1 to 5	Q4 Score	Q4 Ranking	Tier 1 to 5
Perf. Attributes	Level II / III Metrics	2	R	T	4	R	T
Project Control	6.2 Earned and Burned Indicators	1,18	1	1	1,45	4	1
EPCM Agility	5.8 Health, Safety & Environment	1,27	2	1	1,14	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	1,32	3	1	1,32	2	1
Project Control	7.1 Labour (+ Management) Spends	1,36	5	1	1,41	3	1
EPCM Agility	5.2 Schedule Changes	1,32	4	1	1,50	5	1
Project Control	7.2 Equipment + Materials Spends	1,36	6	1	1,59	6	1
Project Control	7.3 Rework Spends	1,50	9	2	1,64	7	1
EPCM Agility	5.1 Schedule (FIWP) Development	1,55	10	2	1,64	8	2
EPCM Agility	5.3 Construction Site Performance				1,64	9	2
EPCM Agility	5.5 Document Control				1,77	14	2
EPCM Agility	3.4 Engineering Reworks & NCR	1,45	7	1	1,64	10	2
EPCM Agility	3.1 Engineering Changes Orders	1,59	12	2			
EPCM Agility	4.1 Material Management at Site	1,68	14	2			
EPCM Agility	3.3 Engineering RFI	1,55	11	2			
EPCM Agility	3.2 Engineering Drawing Changes				1,68	13	2
EPCM Agility	4.4 Inventory Management	1,59	13	2			
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	1,45	8	2	1,64	11	2

Dany Julien (2019)

- Metric 1.5 (Invoice Accuracy) is essential to both owners and contractors, when operating under Time & Materials contracts, especially when LEM (labour, equipment and materials) must be submitted on a daily frequency. For instance, a mega-project which is valued at $1.2B and last for a period of three (3) years, will generate daily amount of $1M in invoices. Hence, the importance for controlling invoices is essential under Time & Materials contracts;

- Metric 3.4 (Engineering Reworks & NCR) is the only EPCM Agility - engineering metrics of importance during Time & Materials contracts, as opposed to the four (4) engineering metrics mentioned in the Lump Sum contracts (3.1, 3.2, 3.3 and 3.4). One would think that controlling change orders and drawing changes are essential to a project success during a Time & Materials contract. However, the results show different assessment from the surveys' participants;

- Metric 5.1 (Scheduled Development) and 5.2 (Schedule Change). These construction metrics emphasise the importance of having strong planning program in order to complete the project on time and on budget;

- Metric 5.8 (Health, Safety & Environment) is once again, one of the most important metrics during a project, where working in a safe and secure job site are very important to projects' success;

- Metric 6.1 Budget (Actual & EAC) and 6.2 (Earned and Burned Indicators) were also important to owners and contractors. Controlling a budget during a mega-project is a very important activity, even under a Lump Sum contract;

- Metric 7.1 (Labour & Management), 7.2 (Equipment & Materials Spends) and 7.3 (Rework Spends) are the last set of metrics that were important to both owners and contractors when operating in Time & Materials contracts. Similarly, as Lump Sum contracts, LEM costs must be controlled and understood, if one wants to achieve project success. In a same approach, the metric of Rework Spends affect both labours costs and potentially new equipment or materials, due to damage or repair. Hence, all three metrics are observed as essential during Time & Materials contracts;

It is further concluded, when considering 2nd Tier level, that these metrics above (1.5, 3.4, 5.2, 5.8. 6.1, 6.2, 7.1, 7.2, 7.3) are to be included in model's artifact. Overall, in terms of the 2nd Tier Level II/III metrics, the artifact (CPPM) shall be represented with the metrics stated in Table 110. This table also demonstrates that participants who took part in the survey did not consider three (3) performance attributes amongst these final 1st and 2nd Tier. These performance attributes that were not selected were: a)

Procurement Responsiveness, b) Workers (Employee) Management, and c) Project Complexity.

Table 4. 111

1st Tier Level II / III Metrics – CPPM

	1st Tier Level II/III - CPPM			1st + 2nd Tier Level II/III - CPPM		
	All Forms of Contract	Lump Sum Contracts	Time & Materials Contract	All Forms of Contract	Lump Sum Contracts	Time & Materials Contract
Procurement Reliability		1.1			1.1	1.5
EPCM Agility	5.2, 5.8	5.1, 5.2, 5.8	5.2, 5.8	3.4, 5.1, 5.2, 5.8	3.1, 3.2, 3.3, 3.4, 5.1, 5.2, 5.8	3.4, 5.2, 5.8
Project Control			6.1, 6.2, 7.1, 7.2	6.1	6.1	6.1, 6.2, 7.1, 7.2, 7.3

Dany Julien (2019)

4.4.6.7. *Final Artifact: 3rd Tier – All Four Contracts*

From a potential of thirty-seven (37) Level II/III metrics that were surveyed, twenty-four (24) of the them were retained as part of the 3rd Tier. Sixteen (16) metrics of these twenty-four (24) metrics observed in the final 3rd Tier were inclusive to all four (4) forms of contracts. This means that sixty-seven (66.7%) percent of the Level III metrics are similar amongst all four (4) scenarios (owners, contractors, Lump Sum and Time & Material contracts). Due to the high level of similarity amongst all types of contracts, this research will not attempt to detail the whys to these results. The 3rd Tier Level II / III metrics are illustrated in Table 4.111.

Table 4. 112
Final 1st, 2nd, 3rd Tier Level II / III Metrics – All Four Contracts

		Q1 - Score	Q1 Ranking	Tier 1 to 5	Q2 Score	Q2 Ranking	Tier 1 to 5	Q3 Score	Q3 Ranking	Tier 1 to 5	Q4 Score	Q4 Ranking	Tier 1 to 5
		Owner LS			Owner T&M			Contractor LS			Contractor T&M		
Perf. Attributes	Level II / III Metrics	1	R	T	2	R	T	3	R	T	4	R	T
Project Control	6.2 Earned and Burned Indicators	2,04	21	3	1,18	1	1	1,57	15	3	1,45	4	1
EPCM Agility	5.8 Health, Safety & Environment	1,22	1	1	1,27	2	1	1,19	1	1	1,14	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	1,65	10	2	1,32	3	1	1,38	3	1	1,32	2	1
Project Control	7.1 Labour (+ Management) Spends	2,00	17	3	1,36	5	1	1,67	19	3	1,41	3	1
EPCM Agility	5.2 Schedule Changes	1,32	3	1	1,32	4	1	1,43	5	1	1,50	5	1
Project Control	7.2 Equipment + Materials Spends	2,00	18	3	1,36	6	1	1,52	10	2	1,59	6	1
Project Control	7.3 Rework Spends				1,50	9	2	1,62	16	3	1,64	7	1
EPCM Agility	5.1 Schedule (FIWP) Development	1,50	7	1	1,55	10	2	1,38	4	1	1,64	8	2
EPCM Agility	5.3 Construction Site Performance	2,00	19	3	1,77	20	3	1,43	6	1	1,64	9	2
EPCM Agility	5.7 Contract / Labour Issues & Solving	1,95	15	3				1,33	2	1	1,86	17	3
EPCM Agility	5.5 Document Control	1,86	14	2	1,77	21	3	1,62	17	3	1,77	14	2
EPCM Agility	3.4 Engineering Reworks & NCR	1,30	2	1	1,45	7	1	1,52	11	2	1,64	10	2
EPCM Agility	3.1 Engineering Changes Orders	1,39	5	1	1,59	12	2	1,52	12	2	1,68	12	2
EPCM Agility	5.4 Turnover & Commissioning	1,48	6	1	1,73	18	3	1,67	20	3	1,86	18	3
EPCM Agility	4.1 Material Management at Site	1,74	11	2	1,68	14	2	1,62	18	3	1,77	15	3
EPCM Agility	3.3 Engineering RFI	1,78	12	2	1,55	11	2	1,48	8	2	1,91	21	3
EPCM Agility	3.2 Engineering Drawing Changes				1,68	15	3	1,52	13	2	1,68	13	2
EPCM Agility	4.4 Inventory Management				1,59	13	2	1,67	21	3			
Project Complexity	12.2 Management Team / Owner Representatives	1,96	16	3	1,73	19	3						
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	2,00	20	3	1,68	16	3	1,52	14	2			
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy										1,77	16	3
Project Integration	13.3 Performance Analytics	1,83	13	2							1,86	19	3
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	1,61	9	2	1,45	8	2	1,62	9	2	1,64	11	2
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	1,35	4	1	1,68	17	3	1,43	7	1	1,86	20	3

Dany Julien (2019)

4.4.6.8. *Final Artifact: 4th Tier – All Four Contracts*

From a potential of thirty-seven (37) Level II/III metrics, thirty-three (33) of them were retained as part of the 4th Tier, and twenty-six (26) metrics of them were observed as inclusive to all four (4) forms of contracts. This means that seventy-nine (78.8%) percent of the Level III metrics were similar amongst all four (4) scenarios (owners, contractors, Lump Sum and Time & Material contracts). Like the 3rd Tier Level II / III metrics stated in the previous section, there are high level of similarities amongst all types of contracts. Thus, this research will not attempt to detail the results for these metrics. The 4th Tier Level II / III metrics are illustrated in Table 4.112.

Table 4. 113
Final 4th Tier Level II / III Metrics – All Four Contracts

Perf. Attributes	Level II / III Metrics	Q1 - Score	Q1 Ranking	Tier 1 to 5	Q2 Score	Q2 Ranking	Tier 1 to 5	Q3 Score	Q3 Ranking	Tier 1 to 5	Q4 Score	Q4 Ranking	Tier 1 to 5
		Owner LS			Owner T&M			Contractor LS			Contractor T&M		
		1	R	T	2	R	T	3	R	T	4	R	T
Project Control	6.2 Earned and Burned Indicators	**2,04**	21	3	**1,18**	1	1	**1,57**	15	3	**1,45**	4	1
EPCM Agility	5.8 Health, Safety & Environment	**1,22**	1	1	**1,27**	2	1	**1,19**	1	1	**1,14**	1	1
Project Control	6.1 Budget (Acutal vs. EAC)	**1,65**	10	2	**1,32**	3	1	**1,38**	3	1	**1,32**	2	1
Project Control	7.1 Labour (+ Management) Spends	**2,00**	17	3	**1,36**	5	1	**1,67**	19	3	**1,41**	3	1
EPCM Agility	5.2 Schedule Changes	**1,32**	3	1	**1,32**	4	1	**1,43**	5	1	**1,50**	5	1
Project Control	7.2 Equipment + Materials Spends	**2,00**	18	3	**1,36**	6	1	**1,52**	10	2	**1,59**	6	1
Project Control	7.3 Rework Spends	**2,14**	26	4	**1,50**	9	2	**1,62**	16	3	**1,64**	7	1
EPCM Agility	5.1 Schedule (FIWP) Development	**1,50**	7	1	**1,55**	10	2	**1,38**	4	1	**1,64**	8	2
EPCM Agility	5.3 Construction Site Performance	**2,00**	19	3	**1,77**	20	3	**1,43**	6	1	**1,64**	9	2
EPCM Agility	5.7 Contract / Labour Issues & Solving	**1,95**	15	3	**1,86**	25	4	**1,33**	2	1	**1,86**	17	3
EPCM Agility	5.5 Document Control	**1,86**	14	2	**1,77**	21	3	**1,62**	17	3	**1,77**	14	2
EPCM Agility	3.4 Engineering Reworks & NCR	**1,30**	2	1	**1,45**	7	1	**1,52**	11	2	**1,64**	10	2
EPCM Agility	3.1 Engineering Changes Orders	**1,39**	5	1	**1,59**	12	2	**1,52**	12	2	**1,68**	12	2
EPCM Agility	5.4 Turnover & Commissioning	**1,48**	6	1	**1,73**	18	3	**1,67**	20	3	**1,86**	18	3
EPCM Agility	4.1 Material Management at Site	**1,74**	11	2	**1,68**	14	2	**1,62**	18	3	**1,77**	15	3
Project Control	8.3 Warehouse / Laydown Spends	**2,32**	28	4				**1,86**	26	4	**2,14**	28	4
Project Control	8.4 Inventory Carrying Costs Spends	**2,30**	27	4							**2,18**	29	5
Project Control	8.1 Transportation Spends				**1,91**	27	4				**2,09**	27	4
EPCM Agility	3.3 Engineering RFI	**1,78**	12	2	**1,55**	11	2	**1,48**	8	2	**1,91**	21	3
EPCM Agility	4.3 Leased Equipment Used at Site				**1,82**	22	4	**1,81**	25	4	**2,00**	25	4
EPCM Agility	3.2 Engineering Drawing Changes	**1,52**	8	2	**1,68**	15	3	**1,52**	13	2	**1,68**	13	2
EPCM Agility	4.4 Inventory Management	**2,09**	25	4	**1,59**	13	2	**1,67**	21	3	**1,95**	23	4
Project Complexity	12.2 Management Team / Owner Representatives	**1,96**	16	3	**1,73**	19	3	**1,86**	27	4	**1,91**	22	4
EPCM Agility	4.2 Transportation Management				**1,91**	28	4						
EPCM Agility	4.5 Bagging / Free Issue to Contractos / Expediting at Site	**2,04**	22	4				**1,95**	28	4			
Procur. Reliability & Responsiveness	2.3 Time to Respond to Procurement Inquiries	**2,00**	20	3	**1,68**	16	3	**1,52**	14	2	**1,95**	24	4
Procur. Reliability & Responsiveness	1.4 Purchase Orders' Quality & Accuracy	**2,04**	23	4	**1,86**	26	4	**1,67**	22	4	**1,77**	16	3
Procur. Reliability & Responsiveness	2.1 Time to Complete Purchase Order Entries	**2,09**	24	4	**1,82**	23	4	**1,76**	24	4	**2,05**	26	4
Project Integration	13.3 Performance Analytics	**1,83**	13	2	**1,82**	24	4	**1,71**	23	4	**1,86**	19	3
Project Control	9.1 Suppliers Spends	**2,57**	35	5	**2,24**	33	5	**2,19**	32	5	**2,50**	37	5
Procur. Reliability & Responsiveness	1.5 Invoices' Accuracy	**1,61**	9	2	**1,45**	8	2	**1,62**	9	2	**1,64**	11	2
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	**2,70**	37	5									
Procur. Reliability & Responsiveness	1.1 Delivery Performance Against Requested Date	**1,35**	4	1	**1,68**	17	3	**1,43**	7	1	**1,86**	20	3

Dany Julien (2019)

4.4.6.9. Final Artifact: 5th Tier

The 5th Tier comprised of the overall thirty-seven (37) Level II/III metrics that were presented to the participants during the survey. Illustrated in Table 4.113 are only the metrics that finished in the overall ranking. These metrics were not viewed as important.

Table 4. 114
Final 5th Tier Level II / III Metrics

Perf. Attributes	Level II / III Metrics	Total Q1 to Q4	Overall Ranking	Tier 1 to 5
		Total	R	T
Project Control	8.4 Inventory Carrying Costs Spends	**2.11**	30	5
Project Control	8.1 Transportation Spends	**2.09**	29	5
Project Control	7.4 IT Integration Spends	**2.51**	37	5
Project Complexity	12.1 Contractor Base Complexity	**2.34**	32	5
Project Control	8.2 Customs Spends	**2.38**	35	5
EPCM Agility	4.2 Transportation Management	**2.14**	31	5
EPCM Agility	5.6 IT Integration Issues & Solving	**2.34**	33	5
Project Control	9.1 Suppliers Spends	**2.37**	34	5
EPCM Agility	4.6 Reverse Logistics (Auction, Surplus, Obsolete)	**2.43**	36	5

Dany Julien (2019)

4.5. ARTIFACTS: CONSTRUCTION PERFORMANCE & PRODUCTIVITY MODEL

After reviewing literatures in supply chain, management information systems, organisational structures and construction management, and proceeding with two (2) residencies through a Participant Observation and an Action Research, followed by a series of semi-structured interviews and one survey, and as well as applying several kernels theories, the researcher formulated its artifact, titled the Construction Performance & Productivity Model (CPPM). This model is grounded on a supply chain framework, meets the research objectives and answers the research questions. The proposed artifact doesn't claim to have the ultimate answer to solve the managerial problems expressed in this doctoral thesis. In general, the CPPM artifact has been designed to cover project activities pertaining to procurement, engineering, construction, cost controls, worker management as well as project complexity and project integration. This thesis' artifact offers three (3) different types of analysis.

First, the CPPM offers to the individuals who are measuring performance and productivity in mega-projects, the availability to use a model with different tier levels (1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}), of which provides the options of monitoring 86, 130, 188, 223 and 305 Level III metrics. Note the 4^{th} and 5^{th} tiers are too cumbersome with their high numbers of metrics and go against the research objectives' easy to use. Table 4.114 illustrates the numbers of metrics potentially available to the individuals measuring performance and productivity with the CPPM.

Table 4. 115
Artifact's Tiers

	Artifact - CPPM				
	CPPM Tier 1	CPPM Tier 2	CPPM Tier 3	CPPM Tier 4	CPPM Tier 5
Performance Attributes (Quantitative)	3	3	5	5	5
Performance Attributes (Qualitative)	0	0	0	1	1
Level I Metrics	4	5	8	10	11
Level II Metrics	7	14	21	28	37
Level III Metrics	86	130	188	223	305

Dany Julien (2019)

Second, the CPPM offers the individuals who are measuring performance and productivity in mega-projects, to select the preferred metrics based on the type of contracts in effect. Table 4.115 illustrates the 1st and 2nd Tier Level II/III metrics under contractual influences. Procurement Reliability, EPCM Agility (Engineering), EPCM (Construction Management) and Project Controls are the dominant performance attributes when considering types of contracts. In addition, the research notes fourteen (14) Level II metrics and 131 Level III metrics.

Table 4. 116 1st + 2nd Tier Level II/III – Types of Contracts

	1st + 2nd Tier Level II/III - CPPM		
	All Forms of Contract	Lump Sum Contracts	Time & Materials Contract
Procurement Reliability		1.1	1.5
EPCM Agility	3.4, 5.1, 5.2, 5.8	3.1, 3.2, 3.3, 3.4, 5.1, 5.2, 5.8	3.4, 5.2, 5.8
Project Control	6.1	6.1	6.1, 6.2, 7.1, 7.2, 7.3

Dany Julien (2019)

Third, the researcher compared both first and second types of analysis at the 2nd Tier level; and was able to determine the similarities between dominant performance attributes and Level I/II/III metrics. These similarities are demonstrated in Table 4.116 and are the following:

- Both types of analysis (overall rankings vs. types of contract) for the 2nd Tier display identical performance attributes.
  - Procurement Reliability, EPCM Agility, Project Controls

- Both types of analysis (overall rankings vs. types of contract) for the 2nd Tier display identical Level I metrics.
  - 1. Delivery Performance;
  - 3. EPCM – Engineering;
  - 5. EPCM – Construction Management;
  - 6. Budget & Planning;
  - 7. LEM Spends.

- Level II metrics differs slightly between the overall ranking and the types of contracts.
  - 5.4 Level II metrics (9 Level III metrics): Turnover & Commissioning is seen as more important on a general level of measurement.
  - 5.3 Level II metrics (23 Level III metrics): Site Performance is seen as more important when considering various types of contracts.
  - 5.8 Level II metrics (17 Level III metrics): Health, Safety & Environment (HSE) is seen as more important on a general level of measurement.
  - 7.3 Level II metrics (4 Level III metrics): Rework Spends is seen as more important when considering various types of contracts.

- The total numbers of Level III metrics available at the 2nd Tier is similar in both types of analysis, with 130 metrics at the general rankings and 132 metrics for the types of contracts.

Table 4. 117
CPPM Similarities

	Construction Performance & Productivuty Model			
	Overall Rankings Tier 2		Types of Contracts Tier 2	
Performance Attributes (Quantitative)	3	Procurement Reliability EPCM Agility Project Controls	3	Procurement Reliability EPCM Agility Project Controls
Performance Attributes (Qualitative)	0		0	
Level I Metrics	5	1, 3, 5, 6, 7	5	1, 3, 5, 6, 7
Level II Metrics	14	1.1, 1.5 3.1, 3.2, 3.3, 3.4 5.1, 5.2, $\boxed{5.4, 5.8}$ 6.1, 6.2 7.1, 7.2	14	1.1, 1.5 3.1, 3.2, 3.3, 3.4 5.1, 5.2, $\boxed{5.3}$ 6.1, 6.2 7.1, 7.2, $\boxed{7.3}$
Level III Metrics	130		131	

Dany Julien (2019)

The next seven (7) sections describe the path of selections for the attributes and metrics when selecting the 2nd Tier Artifact. The selection spans at the start by the enriched SCOR Model, through the semi-structured interviews (Modified SCOR Model) and the survey (CPPM).

4.5.1. Procurement Reliability

The Construction Performance & Productivity Model retained the original SCOR Model's terminology of Procurement Reliability. Prior to commencing the semi-structured interviews, this performance attribute carried one (1) Level I metric, six (6) Level II metrics and forty (40) Level III metrics. From the time the researcher completed the interviews and the survey with all the participants, to the time the CCPM's artifact was designed, a total of two (2) Level II and twenty-six (26) Level III metrics were kept in the final thesis' model. Table 4.117 illustrates the path of selection for the attribute and metrics of Procurement Reliability. Appendix L1 details a complete listing of level III metrics belonging to the attribute of Procurement Reliability.

Table 4. 118
Path of Metrics' Selection – Procurement Reliability

Interviews (Enriched SCOR Model)			
1	1	6	40
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
I. Procurement Reliability	1. Delivery Performance	1.1. Scheduled Purchase Orders Made by Owner's Request 1.2. Delivery Performance Against Owner's Requested Date 1.3. Delivery Performance by Suppliers' Committed Date 1.4. Perfect Orders' Fulfillment 1.5 Purchase Orders' Quality & Accuracy 1.6 Invoices' Accuracy	1.1: 10 metrics 1.2: 6 metrics 1.3: 5 metrics 1.4: 2 metrics 1.5: 7 metrics 1.6: 10 metrics Total: 40 metrics

Survey (Modified SCOR Model)			
1	1	4	38
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
I. Procurement Reliability	1. Delivery Performance	1.1. Delivery Performance Against Owner's Requested Date 1.2. Delivery Performance by Suppliers' Committed Date 1.4 Purchase Orders' Quality & Accuracy 1.5 Invoices' Accuracy	1.1: 16 metrics 1.2: 5 metrics 1.4: 7 metrics 1.5: 10 metrics Total: 38 metrics

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
1	1	2	26
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
I. Procurement Reliability	1. Delivery Performance	1.1. Delivery Performance Against Owner's Requested Date 1.5 Invoices' Accuracy	1.1: 16 metrics 1.5: 10 metrics Total: 26 metrics

Dany Julien (2019)

Level I Metric: the terminology from the original SCOR's expression Delivery Performance & Perfect Order Fulfillment were combined into one (1) term in the CPPM's artifact: Delivery Performance.

Level II metrics: Metric 1.1 (Scheduled Purchased Orders Made by Owners' Request) and metric 1.2 (Delivery Performance against Owner's Requested Date) were combined as one metric into metric 1.1 (Delivery Performance against Owner's Request). This metric combination resulted into sixteen (16) Level III metrics. From the participants' scores, only Level II metric 1.1 (Delivery Performance against Owner's Request) and 1.5 (Invoices' Accuracy) have displayed a level of robustness in the proposed CPPM's artifact.

Level III Metrics: Procurement Reliability contains in total forty (40) Level III metrics at the beginning of the interviews. From the two (2) Level II metrics that were retrained, a total of twenty-six (26) Level III metrics are represented in the

Construction Performance & Productivity Model. These Level III metrics are comprised of metric 1.1 (16 metrics) and metric 1.5 (10 metrics).

4.5.2. Procurement Responsiveness

The Construction Performance & Productivity Model retained the original SCOR Model's terminology of Procurement Responsiveness. Prior to commencing the interviews, this performance attribute had one (1) Level I metric, three (3) Level II metrics and eleven (11) Level III metrics. From the time the researcher completed the interviews and the survey, to the time the CCPM's artifact was designed, none of the Level II nor Level III metrics were retained for the design of the final thesis' artifact. Table 4.118 illustrates the path of selection for the attribute and metrics of the Procurement Responsiveness. Appendix L2 details a complete listing of level III metrics belonging to the attribute of Procurement Responsiveness.

Table 4. 119
Path of Metrics' Selection – Procurement Responsiveness

Interviews (Enriched SCOR Model)			
1	1	3	11
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
II. Procurement Responsiveness	2. Purchase Order Fulfillment Cycle Time	2.1 Purchase Order Entry Completed 2.2 Invoice Received at Owner 2.3 Inquiry Time - Procurement	2.1: 5 metrics 2.2: 4 metrics 2.3: 2 metrics Total: 11 metrics

Survey (Modified SCOR Model)			
1	1	2	7
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
II. Procurement Responsiveness	2. Purchase Order Fulfillment Cycle Time	2.1 Purchase Order Entry Completed 2.3 Inquiry Time - Procurement	2.1: 5 metrics 2.3: 2 metrics Total: 7 metrics

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
0	0	0	0
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
N/A	N/A	N/A	N/A

Dany Julien (2019)

Level I Metric: The Level I metric named Purchase Order Fulfillment Cycle Time is identical to the one utilised in the SCOR model.

Level II / III Metrics: The model started originally with three (3) metrics and were reduced to two (2) Level II metrics during the survey. None of the Level II metrics, and subsequently Level III metrics were retained as being robust for the final CPPM design.

4.5.3. EPCM Agility

The Construction Performance & Productivity Model did not retain the original SCOR Model's performance attribute that was named Supply Chain Agility. Instead, the researcher changed the attribute's name to EPCM Agility, which reflected the overall projects' activities during construction of mega-projects. The EPCM Agility covers primarily three (3) activities, which are engineering, field procurement and construction management. Prior to the interviews, there were three (3) Level I metrics, nineteen (19) Level II metrics and 161 Level III metrics. From the time the researcher completed the interviews and the survey, to the time the CCPM's artifact was designed, the researcher kept for the final thesis' artifact a total of two (2) Level I metrics were kept, eight (8) Level II metrics and seventy-five (75) Level III metrics. Table 4.119 illustrates the path of selection for the attribute and metrics for the performance attribute of EPCM Agility. Appendix L3 details a complete listing of level III metrics belonging to the attribute of EPCM Agility.

Level I metrics: The reader should note there was a changed after the interviews, where the two categories named construction and management were combined into one expression called construction management. After the interviews and the survey were conducted, both engineering and construction metrics were kept but the field procurement metric was not retained in the final thesis' model.

Level II metrics: All Level II metrics survived the robustness test after the interviews and survey. However, the Construction Performance & Productivity Model retained only eight (8) Level II metrics that were ranked in the 1st and 2nd Tier, whose both robustness was important to the owners and contractors. The metrics that were retained included the engineering (3.1, 3.2, 3.3, 3.4) and the construction management (5.1, 5.2, 5.4, 5.8). The reader should also note that metric 3.4 (Engineering Rework) and metric 3.5 (NCR) were combined into one metric (3.4 – Engineering Reworks & NCR) during the survey and accounted together for twenty-two (22) Level III metrics.

Level III metrics: The Level III metrics were reduced by more than half from the original model, decreasing from 161 metrics down to 75 metrics.

Table 4. 120
Path of Metrics' Selection – EPCM Agility

Interviews (Enriched SCOR Model)			
1	3	19	161
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
III. EPCM Agility	3. "E" Engineering 4. "P" Procurement 5. "CM" Construction Management	3.1 Engineering Changes 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks 3.5 Quality - NCR 4.1 Material Management 4.2 Transportation Management 4.3 Leased Equipment Availability 4.4 Inventory Management 4.5 Bagging / Expediting at Site 4.6 Reverse Logistics 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning 6.1 Document Control 6.2 Information Technology 6.3 Contract & Labour 6.4 Health, Safety & Environment	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 4 metrics 3.5: 18 metrics 4.1: 19 metrics 4.2: 6 metrics 4.3: 3 metrics 4.4: 5 metrics 4.5: 4 metrics 4.6: 3 metrics 5.1: 12 metrics 5.2: 5 metrics 5.3: 23 metrics 5.4: 9 metrics 5.5: 2 metrics 5.6: 4 metrics 5.7: 8 metrics 5.8: 17 metrics Total: 161 metrics

➡

Survey (Modified SCOR Model)			
1	3	18	161
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
III. EPCM Agility	3. "E" Engineering 4. "P" Procurement 5. "CM" Construction Management	3.1 Engineering Changes Orders 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks & NCR 4.1 Material Management 4.2 Transportation Management 4.3 Leased Equipment Availability 4.4 Inventory Management 4.5 Bagging / Expediting at Site 4.6 Reverse Logistics 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning 5.5 Document Control 5.6 Information Technology 5.7 Contract & Labour 5.8 Health, Safety & Environment	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 22 metrics 4.1: 19 metrics 4.2: 6 metrics 4.3: 3 metrics 4.4: 5 metrics 4.5: 4 metrics 4.6: 3 metrics 5.1: 12 metrics 5.2: 5 metrics 5.3: 23 metrics 5.4: 9 metrics 5.5: 2 metrics 5.6: 4 metrics 5.7: 8 metrics 5.8: 17 metrics Total: 161 metrics

⬇

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
1	2	8	75
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
III. EPCM Agility	3. "E" Engineering 5. "CM" Construction Management	3.1 Engineering Changes Orders 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks & NCR 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.4 Turnover & Commisioning 5.8 Health, Safety & Environment	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 22 metrics 5.1: 12 metrics 5.2: 5 metrics 5.5.8: 17 metrics Total: 75 metrics

Dany Julien (2019)

4.5.4. Project Controls

The Construction Performance & Productivity Model did not retain the original SCOR Model's terminology called Supply Chain Costs. Instead, the researcher changed the name of the performance attribute to Project Controls, which is more in line with construction projects' activities and their related costs.

Prior to the interviews, there were four (4) Level I metrics, twelve (12) Level II metrics and fifty-two (52) Level III metrics. From the time the researcher completed the interviews and the survey, to the time the CCPM's artifact was designed, two (2) Level I metrics, four (4) Level II and twenty (20) Level III metrics were kept in the final thesis' artifact. Table 4.120 illustrates the final metrics for the attribute and metrics for Project Controls. Appendix L4 details a complete listing of level III metrics belonging to the attribute of Project Controls.

Level I metrics: Project Controls includes Level I metrics such as Budget & Planning, LEM spends, Logistics Spends and Processing Spends. These cost metrics reflect the activities that must be accounted for during any construction project. The last two spends (Logistics and Processing) were not retained in the final CPPM's artifact.

Level II metrics: Both Budget & Planning's Level II metrics were retained for the CPPM's artifact. For the LEM Spends, only four (4) Level II metrics were retained out of a possible four (4) metrics.

Level III metrics: A total of twenty (20) Level III metrics were retained, from a potential selection of fifty-two (52) metrics at the beginning.

Table 4. 121
Path of Metrics’ Selection – Project Controls

Interviews (Enriched SCOR Model)			
1	4	12	52
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
IV. Project Controls	6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends	7.1 Budget (Actual vs. EAC) 7.2 Earned & Burned Indicators 8.1 Labour & Management Spends 8.2 Material/ Equipment Spends 8.3 Rework Spends 8.4 IT Integration Spends 9.1 Transportation Spends 9.2 Customs Spends 9.3 Warehouse / Laydown Spends 9.4 Inventory Carrying Costs 10.1 Suppliers Spends 10.2 Purchase Order Costs	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics 7.3 4 metrics 7.4 1 metrics 8.1 6 metrics 8.2 2 metrics 8.3 3 metrics 8.4 7 metrics 9.1 6 metrics 9.2 3 metrics Total = 52 metrics

Survey (Modified SCOR Model)			
1	4	11	49
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
IV. Project Controls	6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends 7.3 Rework Spends 7.4 IT Integration Spends 8.1 Transportation Spends 8.2 Customs Spends 8.3 Warehouse / Laydown Spends 8.4 Inventory Carrying Costs 9.1 Suppliers Spends	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics 7.3 4 metrics 7.4 1 metrics 8.1 6 metrics 8.2 2 metrics 8.3 3 metrics 8.4 7 metrics 9.1 6 metrics Total = 49 metrics

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
1	2	4	20
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
IV. Project Controls	6. Budget & Planning 7. LEM Spends	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics Total = 20 metrics

Dany Julien (2019)

4.5.5. Workers (Employees) Management

The researcher understands that construction job sites are human-driven, and measuring asset management is irrelevant to the construction communities. Thus, the performance attribute named Supply Chain Asset Management, found in the SCOR Model was replaced by a new terminology called Workers (Employee) Management. The researcher believes the primary asset in a construction mega-project are the crews and the management staff, including consultants and owners’ representatives. The performance attribute was initially called Workers Information during the interviews, then to be changed for Workers (Employees) Management, while conducting the survey.

Initially, the Level I metric for this performance attribute consisted of only one (1) metric; whereas the Level II metrics for this attribute were comprised of two (2) metrics – one for workers-tradesmen and one more for the management staffs. Finally, the Level III metrics included twenty-three (23) metrics at the beginning of the interviews.

None of the Level II and III metrics survived the robustness tests after the interviews, nor the survey. Hence, the Construction Performance & Productivity Model did not retain these metrics amongst its 1st and 2nd tier of importance. Table 4.121 illustrates the path of selection for the CPPM design, which none of the Level I/II/III metrics were retained for the final artifact. Appendix L5 details a complete listing of level III metrics belonging to the attribute of Workers (Employee) Management.

Table 4. 122
CPPM Metrics – Workers (Employees) Management

Interviews (Enriched SCOR Model)			
1	1	2	23
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
V. Employee Management	10. Workers Information	11.1 Labour Force's Information 11.2 Management Information	10.1 13 metric 10.2 10 metric Total = 23 metrics

Survey (Modified SCOR Model)			
1	0	0	0
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
V. Employee Management	N/A	N/A	N/A

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
0	0	0	0
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
N/A	N/A	N/A	N/A

Dany Julien (2019)

4.5.6. Project Complexity

The performance attribute named Supply Chain Complexity in the SCOR Model was replaced in the CPPM by the terminology called Project Complexity. The researcher expressed the importance of a project complexity into two (2) environment: first, the activities that occur off-site such as the distribution network for obtaining materials and equipment and, second, job-site complexity where, for instance, workers' congestions have an effect on tasks; efficiencies.

Level I metrics: Hence, the Project Complexity’s Level I metrics consisted of two (2) metrics: a) Off-Site Complexity, and b) Job-Site Complexity. During the interviews, the participants, noted the importance of the job-site complexity, but not so much for the off-site complexity, especially once the project started. None of the Level I metric was retained in the final CPPM’s artifact.

Level II metrics: The Off-Site Complexity consisted of four (4) Level II metrics and two (2) Level II metrics for the Job-Site Complexity. None of the Level II metric was retained in the final CPPM’s artifact.

Level III metrics: This attribute carried a total of seventy-nine (79) Level III metrics during the interviews, of which there were nineteen (19) are related to the Off-Site Complexity and sixty (60) of them were classified as Job-Site Complexity. None of the Level III metric was retained in the final CPPM’s artifact.

Table 4.122 illustrates the path of selection for the CPPM design, which none of the Level I/II/III metrics were retained for the final artifact. Appendix L6 details a complete listing of level III metrics belonging to the attribute of Project Complexity.

Table 4. 123
Path of Metrics’ Selection – Project Complexity

Interviews (Enriched SCOR Model)			
1	2	6	79
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
VI. Project Complexity	11. Off-Site Complexity 12. Job Site Complexity	12.1 Manufacturing Complexity 12.2 Distribution Complexity 12.3 Supplier Base Complexity 12.4 IT Base Complexity 13.1 Contractor Base Complexity 13.2 Management Team / Owner Representatives	11.1 2 metrics 11.2 9 metrics 11.3 3 metrics 11.4 5 metrics 12.1 47 metrics 12.2 13 metrics Total = 79 metrics

Survey (Modified SCOR Model)			
1	1	2	60
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
VI. Project Complexity	12. Job Site Complexity	12.1 Contractor Base Complexity 12.2 Management Team / Owner Representatives	12.1 47 metrics 12.2 13 metrics Total = 60 metrics

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
0	0	0	0
Performance Attributes	**Level I Metrics**	**Level II Metrics**	**Level III Metrics**
N/A	N/A	N/A	N/A

Dany Julien (2019)

4.5.7. Project Integration

The performance attribute named Supply Chain Maturity in SCOR Model is replaced by Project Integration in CPPM. As discussed in prior chapter, a project maturity can't be measured due to its uniqueness and short period of execution, whereas manufacturing industries have years of history and archive to explore with.

Level I metrics: The Level I metrics for Project Integration consists of one (1) metric with the name of Project Analytics. The purpose for this metric was to explore the likelihood to introduce analytics in the construction culture. As recorded during the interviews' remarks, they were two polarizing views with construction analytics, depending on the age of the participants. The younger participants embraced the new world of analytics, whereas the older participants (50+) brought caution to try to micro-manage construction activities. Notwithstanding the views above, none of the Level I metrics was retained in the CPPM's artifact.

Level II and III Metrics: The researcher presented the potential to use performance analytics tools with the integration of performance attributes between Level II and III metrics. As for Level I, none of the Level II and III were retained for the Construction Performance & Productivity Model. Table 4.123 illustrates the path of selection for the CPPM design, which none of the Level I/II/III metrics. Appendix L7 details a complete listing of level III metrics belonging to the attribute of Project Integration.

Table 4. 124
Path of Metrics' Selection – Project Integration

Interviews (Enriched SCOR Model)			
1	1	2	366
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
VII. Project Integration	13. Performance Analytics	14.1 Level II / III metrics 14.2 Performance Analytics	366 metrics

Survey (Modified SCOR Model)			
1	1	2	366
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
VII. Project Integration	13. Performance Analytics	13.1 Level II / III Metrics 13.2 Performance Analytics	366 metrics

Construction Performance & Productivity Model Artifact: 1st & 2nd Tier			
0	0	0	0
Performance Attributes	Level I Metrics	Level II Metrics	Level III Metrics
N/A	N/A	N/A	N/A

Dany Julien (2019)

4.5.8. Conclusion – Artifacts' Performances

The Construction Performance & Productivity Model offers a different approach then the SCOR Model. As discussed in prior sections, the SCOR Model is partially effective in measuring the early activities of construction project management, such as procurement. Otherwise, the SCOR Model failed to measure critical engineering and construction activities, such as field management, cost control, project complexities and integration. Nonetheless, the prime reason for using the SCOR Model as a benchmark, is based on its supply chain framework, which provides a common language in business process.

To do so, the CPPM targets the three (3) most complex phases during a project, which are the Front-End Planning, the Detailed-Engineering and Construction. Henceforward, the CPPM framework facilitate a horizontal process integration across the phases of construction project management. Subsequently, in order to validate the value of this proposed artifact, the researcher combined the 1st and 2nd Tier for the rankings of the metrics and the rankings by types of contracts. Both types of analysis resulted in identical performance attributes and Level I metrics and the same amount of Level II metrics. The researcher demonstrates the results in Table 4.124.

Table 4. 125
CPPM Similarities

	Construction Performance & Productivuty Model			
	Overall Rankings Tier 2		Types of Contracts Tier 2	
Performance Attributes (Quantitative)	3	Procurement Reliability EPCM Agility Project Controls	3	Procurement Reliability EPCM Agility Project Controls
Performance Attributes (Qualitative)	0		0	
Level I Metrics	5	1, 3, 5, 6, 7	5	1, 3, 5, 6, 7
Level II Metrics	14	1.1, 1.5 3.1, 3.2, 3.3, 3.4 5.1, 5.2, 5.4, 5.8 6.1, 6.2 7.1, 7.2	14	1.1, 1.5 3.1, 3.2, 3.3, 3.4 5.1, 5.2, 5.3 6.1, 6.2 7.1, 7.2, 7.3
Level III Metrics	130		131	

Dany Julien (2019)

For the first part of the research question: *"While integrating a supply chain framework processes (end-to-end) in construction project management, which performance attributes and metrics are essential to a model having the objective of attenuating the managerial problems of cost overruns and late deliveries, while considering four (4) types of construction contracts?"* By combining the "General Ranking" with the ranking from the "Types of Contracts" obtained in a 1st and 2nd Tier option, the researcher obtained the following results, as described in Table 4.125:

a. The performance attributes that performed best in the CPPM's artifact (1st & 2nd Tier) were Procurement Reliability, EPCM Agility, and Project Controls;

b. Level I: 40% of the Level I metrics belonged to the performance attributes of EPCM Agility and Project Controls, whereas 20% of the Level I metrics belong to the performance attribute of Procurement Reliability. Delivery Performance, EPCM-Engineering, EPCM-CM, Budget & Planning and LEM Spends were the most sought level I metrics for this artifact;

c. Level II: Both general rankings and types of contracts resulted in fourteen (14) Level II metrics each. However, when combining the "contract metrics" (5.3, and 7.3) to the "general ranking" metrics, the final Level II metrics for the artifact has a total sixteen (16) of them. The most important Level II metrics were the ones belonging to the performance attributes of EPCM Agility (56%), followed by Project Controls at 31% and Procurement Reliability with 13%;

d. Level III: Both general rankings and types of contracts resulted in 130 and 131 Level III metrics, respectively. However, when combining the "contract metrics" (5.3, and 7.3) to the "general ranking" metrics, the final Level III metrics for the artifact has a total 157 of them. The most important Level II metrics were the ones belonging to the performance attributes of EPCM Agility (68%), followed by Procurement Reliability (17%) and Project Controls (15%).

Table 4. 126
Combined "General Ranking" + "Types of Contracts": 1st & 2nd Tier

Construction Performance & Productivity Model Combined "General Rankings" + "Types of Contracts": 1st & 2nd Tier							Combined Strenght
2nd Tier: 3	2nd Tier: 5		2nd Tier: 16		2nd Tier: 157		
Performance Attributes	Level I Metrics	% (I)	Level II Metrics	% (II)	Level III Metrics	% (III)	%
I. Procurement Reliability	1. Delivery Performance	20%	1.1. Delivery Performance Against Owner's Requested Date 1.5 Invoices' Accuracy	13%	1.1: 16 metrics 1.5: 10 metrics Total: 26 metrics	17%	16%
III. EPCM Agility	3. "E" Engineering 5. "CM" Construction Management	40%	3.1 Engineering Changes Orders 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks & NCR 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning 5.8 Health, Safety & Environment	56%	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 22 metrics 5.1: 12 metrics 5.2: 5 metrics 5.3: 23 metrics 5.4: 9 metrics 5.8: 17 metrics Total: 107 metrics	68%	55%
IV. Project Controls	6. Budget & Planning 7. LEM Spends	40%	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends 7.3 Reworks Spends	31%	6.1: 8 metrics 6.2: 3 metrics 7.1: 4 metrics 7.2: 5 metrics 7.3: 4 metrics Total = 24 metrics	15%	29%

Dany Julien (2019)

For the second part of the research question: "*Subsequently, in this proposed supply chain-driven model, is there a certain dominance of performance attributes and metrics belonging more to engineering, procurement or construction activities?*"

a. Although the researcher intentionally design the artifact with a supply chain framework, the EPCM (engineering and construction management) Level I/II/III metrics dominated the robustness of the Construction Performance & Productivity Model with a combined strength of 55%, followed by the Project Controls (29%) and Procurement Reliability (16%). The results are shown in Table 4.125;

b. Although the CPPM is based on a supply chain framework, the level of supply chain robustness represented by procurement metrics in either categories such as a) Procurement Responsiveness, b) Procurement Reliability, c) EPCM –

Procurement and d) Project Controls; is marked by a low representation throughout the model. Hence, the model is not subjective to the research's affinity with supply chain activities. The results are shown in Table 4.125. For instance:

- Procurement Reliability displays a combined strength of 16%;

- Procurement Responsiveness shows 0% robustness in the final artifact;

- EPCM - Procurement (section 4) of the Level II/III metrics shows 0% robustness in the final artifact;

- The only procurement metric in Project Control that was retained in the final artifact is 7.2 (Material Equipment Spends) with five (5) Level III metrics, representing 3% in the overall artifact.

a. The low representation of supply chain metrics in the CPPM (combined robustness of 16%) correlates with the results of the Participant Observation that were obtained during the Project Flow Analysis, where only 27% of the activities were related to supply chain;

b. The low representation of supply chain metrics in the CPPM (combined robustness of 16%) correlates with the results with the Action Research, where the inventory accuracies were poorly maintained by the Prime Contractor.

   - The correlation stems with the Instrumentation Department inaccuracies rated at 82.8% (robustness of 17.2%).
   - The research noted the Electrical Department's inaccuracies rate at 15% (robustness of 85%) and the Mechanical Department's inaccuracy of 37% (robustness of 53%).

In conclusion, the researcher combined the 1st and 2nd Tier for the rankings of the metrics and the rankings by types of contracts. The same exercise can be done with the proposed artifact, while selecting and comparing either 1st, 2nd, 3rd, 4th and 5th Tier metrics. At last, the researcher believes the CPPM meets the research objectives and answers both research questions. Moreover, this artifact is an improvement over the SCOR Model as it brings to mega-projects news solutions (metrics) for the known managerial problems in construction. Finally, the researcher concludes through its results that the CPPM offers some research opportunities and knowledge contributions to the construction industry. Validation, limitations and research opportunities is described in the next sections.

4.6. VALIDATION

The validation processes Design-Science Research focus on evaluating the CPPM's artifact in the context of mega-projects within the construction industry. The evaluation must as well, also regard the artifact in the context of the knowledge (design and science) it contributes to the construction industry (Hevner *et al.*, 2004). According to Vendable *et al*. (2016), an artifact validation, such as the evaluation of the Construction Performance & Productivity Model, can be done through laboratory experiments, pilot applications (i.e. instantiation of prototypes), simulation procedures, expert reviews, and field experiments. Other authors such as Österle *et al.* (2010), state that artifact can be designed from axioms, guidelines, frameworks, norms, patents, software (with open source code), business models, enterprise start-ups, and much more.

4.6.1. Process Validation

The Construction Performance & Production Model is made up of cross-method frameworks (Baskerville *et al*., 2015; Sein *et al*., 2011), such as knowledge obtained from a Participant Observation, an Action Research, a set of semi-structured interviews and a survey made up of senior management. The proposed model has a broader purpose than in the ordinary practice of design (Venable *et al*., 2016). From these observations obtained, the design process for the CPPM targeted which attributes and metrics were to be kept in order to meet the design objectives, such as:

- The implementation of a supply chain approach as the basics framework for the model proposed;
- By offering a construction model that is friendly to use by construction stakeholders; and provide performance attributes and metrics, which are useful to construction specialists;
- Filling the literature gap in construction project management, by offering a model that covers all phases and activities of construction mega-projects;

- By providing real-time measurement at construction site, which will help forecasting projects' costs and delivery scheduled throughout the construction phase;

- The model must adapt to several types of construction contracts, such as time & materials (cost plus) and lump sum contracts.

This research focused its objectives, along with the Design-Science Research (DSR) approach, (a) by designing an artifact (Construction Performance & Productivity Model) that covers the essential activities of procurement, engineering, construction, cost control, employee management and project complexities during mega-projects; and (b) by supporting the DSR with various temporary kernel theories related to construction management.

According to Osterle *et al*. (2010), a Design-Science Research follows an iterative process validation comprising of four basic phases: a) analysis, b) design, c) evaluation and d) diffusion.

- As part of the design science process, the analysis is tightly coupled with the constructs, observations (participative and action research), data, reviews of literature, semi-structured interviews and a survey;

- Then, a design, in this case, a supply chain framework was formulated, based on the previous analysis, research questions and the research objectives;

- Third, the evaluation of the enriched SCOR Model was undertaken, qualitatively and quantitatively, whereas a Modified SCOR Model resulted into the CPPM;
- Finally, the model's design must be diffused for critics.

Thus, without sound process validation of the model's artifact, a Design-Science Research must conclude, with only theorising about the utility of its artifact, that is, with an assertion that our research model works without any evidence that it does (Osterle *et al*., 2010).

The researcher concludes, thus far, that the Construction Performance & Productivity Model has shown to the reader that the analysis and the design of a Design-Science Research were met, through:

a. Successfully completed the "analysis" through the review of literature, establishing constructs, the results obtained during the Participant Observation (Project Flow Analysis), the results obtained from the Action Research (Inventory Control); and the results from the semi-structured interviews and one survey;

b. Successfully completed its "design" by electing the most robust performance attributes, Level I, II, III metrics for its artifact, through the selection of its 1^{st}, 2^{nd}, 3^{rd}, 4^{th} or 5^{th} tier;

c. The researcher successfully completed its "diffusion" by writing this doctoral thesis;

d. In terms of the last remaining validation process of "evaluation" for the Design-Science Research, the following sections in this chapter will discuss it.

4.6.2. DSR Principles

Along with respecting the process of analysing, designing, evaluating and diffusing the artifact, a Design-Science Research must also comply with four (4) basic principles: a) abstraction, b) originality, c) justification and d) benefit.

4.6.2.1. Abstraction

The artifact must be applicable to a class of problems, an idea rather than a specific event. Hence the abstraction for this model's artifacts deals with cost overruns and late deliveries during mega-projects. Review of literatures provides several reasons for this kind of problems to occur during mega-projects. Several solutions exists, however none of them are holistic, hence the managerial problems in mega-projects remain open for research opportunities.

4.6.2.2. Originality

Although the Construction Performance and Productivity Model (CPPM) utilises a similar framework from the SCOR (Supply Chain Operations Reference) Model, the originality of the CPPM is reflected by the coverage of all related activities to construction project management, starting from the Conceptual Phase, then moving on to the Front-End Planning, Detailed Engineering and Construction Phase.

In addition, the performance attributes from the original model were also enriched, modified and minimised in order to reflect the performance attributes of mega-projects. Finally, the Level I, II and III metrics were also reviewed, modified or minimised from their original format (SCOR Model) and reflected the complexity and the dynamic environment of all phases during construction project management.

4.6.2.3. Justification

The thesis' artifact must be justified in a comprehensible manner and must allow for its validation. The Design-Science Research process does not share the uniformity of a design study, nor does it share the uniformity of a scientific study (Baskerville *et al.,* 2015). During Participant Observation (PA) and Action Research (AR), the researcher works as a designer and a researcher in an attempt to solve the managerial problems of cost overruns and late deliveries during mega-projects.

The researcher also reviewed several kernels theories, allowing for science to take part in this artifact. Then through semi-structured interviews and the survey, the researcher attempted to decipher information amongst participants, and subsequently design the model's artifact for this research.

Through the Design-Science Research (DSR) approach, the researcher was able to develop an artifact and produce knowledge about important performance attributes and metrics, which is in line with the research conducted by Baskerville *et al.,* 2015. This model's artifact is also coherent with the centrality of knowledge production in DSR. By providing several layers of metric tiers (1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}), the artifact provides to its users several options of robustness to choose from.

4.6.2.4. Benefits

The artifact must yield one or several benefits, either immediately or in the future, for its respective stakeholders. The researcher doesn't believe the CPPM design is the holistic solution for all mega-projects' problems. However, the CPPM's artifact (1^{st}, 2^{nd} tier) provides performance attributes and metrics which makes the measurement of performance and productivity much more accurate during mega-projects. The CPPM also provides the benefits of expanding the number of metrics by selecting 3^{rd}, 4^{th} or 5^{th} Tier Level II / III metrics. The researcher understands, though, the cumbersome of using 3^{rd}, 4^{th}, and 5^{th} Tier metrics, unless automated with BI tools.

In terms of its science view, the model's artifact is solidly based on several temporary kernel theories, which offers an array of opportunities for future research. Kernels theories included an economic approach (RBV, Dynamic Capabilities), theories of IT adoption (TAM, management information systems), organisational theories (Co-Alignment, Concept of the Fit, Contingency Theories) and design-science theories (Structuration of Theory of Duality, DSR). The researcher concludes its artifact (Construction Performance & Productivity Model) has met the four (4) principles pertaining to Design-Science Research.

4.6.3. Evaluations of the Artifact

Evaluation is crucial to Design-Science Research and requires that its researchers to rigorously demonstrate the utility, quality, and efficacy of a design artifact using well-executed evaluation methods (Hevner *et al.,* 2004). This thesis has selected a naturalistic evaluation, which derives strength in its internal validity from the actual performance of the artifact (e.g. CPPM) against its intended environment (e.g. mega-project).

So, the proposed Construction Performance & Productivity Model's artifact for this thesis is validated by (1) a design and (2) provide new theoretical grounding, such as offered by its various kernel theories described in the previous section. According to Vaishnavi *et al*., 2004, the artifact must be analysed for its uses and performance, as well as providing explanations for changes.

In a sense, this kind of build-and-evaluate cycle offer by the Design-Science Research seeks to deliver both environmental utility (understanding construction projects management processes) and knowledge production (which attributes and metrics are important to owners and contractors). So, the naturalistic evaluation's approach not only needs to address the quality of the CPPM's artifact utility, but also the quality of its knowledge outcomes (level of robustness of the performance attributes and metrics during Lump Sum or Time & Material contracts).

Other authors such as Davis (2005), states the contributions of a design artifact, such the ones elaborated in the CPPM, may be evaluated by: a) reasoning, b) proof of concept, c) proof of value added, or d) proof of acceptance and use. In addition, Vendable *et al.* (2016) state the validity and strength of an evaluation study for a Design-Science Research is situated in the paradigm of the evaluation and how it evaluates the artifact's achievement of its intended purpose (research question and research objectives). Overall, Venable *et al*., (2016) reaffirm an evaluation should be relevant, rigorous, and scientific. In order to pursue this view, this thesis adopts the six (6) purposes of evaluation offered by Venable *et al*. (2016):

4.6.3.1. Environmental Utility

First, one key purpose of conducting an evaluation in DSR is to determine how well a designed artifact will achieve its expected "environmental utility" (understanding construction projects' problems). In other words, the researcher tries to determine how well its design's (e.g.: CPPM) will measure the performance and productivity during mega-projects, using specific performance attributes and metrics that are related to construction project management.

- The framework of the artifact (e.g. CPPM) has been based starting at the onset of the thesis, from the SCOR Model, then enriched, modified and supplemented with performance attributes and metrics that are in lined with todays' construction mega-projects;

- The CPPM design covers all five (5) phases of construction project management, including seven (7) performance attributes such as: procurement reliability, procurement responsiveness, EPCM agility, project controls, employee management, project complexity and project integration;

- Level I, II and III metrics were carefully analysed for being pertinent to mega-projects' activities, including procurement, engineering, construction management, project controls, employee management, project complexities and integration. For instance, SCOR Model measures approximately 250 Level III metrics, whereas the enriched SCOR Model resulted with 366 Level III metrics;

- The CPPM framework has been reinforced with reviews of literatures, constructs, semi-structured interviews, one survey, kernels theories and remarks recorded with senior construction and engineering staffs that evolved in mega-projects.

The researcher concludes the Construction Performance & Productivity Model achieves its expected environmental utility during construction of mega-projects and offer a new way of measuring costs and deliveries.

4.6.3.2. Substantiation

Second, a key purpose of the DSR evaluation is the "substantiation" of its design theory in terms of the quality of its knowledge outcomes (Baskerville *et al.*, 2007; Kuechler *et al*., 2012). The substantiation of the design theory provides evidence that kernels theories led to a proposed artifact that will be useful for solving one or several managerial problems or making any kind of improvement.

- In relation to substantiation, the researcher is not concerned so much about proving a specific law or theory which would explain why mega-projects are plagued with cost overruns and late deliveries. Instead, the researcher provides an artifact that is readable, friendly and usable to the average senior management involved with mega-projects;

- Design-Science Research (DSR) espouses academic freedom in science and real-life environment (Vendable *et al*., 2016). Design-Science Research does not rely on one specific theory but rather on an approach to theory construction, known as mid-range theory. A mix of temporary kernel theories make up the mid-range theory that will grow into new mid-range theory, as the artifact goes through evolution in time;

- In accordance with Merton (1968) and Boudon (1991), mid-range theories are normally constructed by applying theory-building techniques (kernels theories) to empirical research, which produce generic propositions about the social world, which in turn can also be empirically tested;

- Although the model's artifact was built with a supply chain approach, the strongest performance attributes and metrics amongst resulted with engineering and construction metrics;

- The engineering and construction culture prevail during mega-projects, and the managerial problems enumerated in this thesis are not about to be solved solely by introducing a supply chain framework;

- As displayed by the survey's results, 1st and 2nd Tier Level II/III metrics pertaining to engineering and construction performance attributes outshined all other metrics amongst all four (4) types of construction contracts.

The researcher concludes the substantiation of the Construction Performance & Productivity Model provides quality knowledge outcomes, due to the quality of the participants in the semi-structured interviews and survey.

4.6.3.3. Comparative Evaluation

Third, an evaluation is concerned with undergoing a "comparative evaluation" of the new artifact/design theory in comparison with other artifact/design theory (Venable, 2006). This comparative evaluation is intended to determine whether the new CPPM makes an improvement over the current literature, marked with the SCOR Model.

- The researcher's CPPM design is originally based on the SCOR Model, also known as the Supply Chain Operations Reference Model, formulated by the Council of Supply Chain Management, located in the United States of America;

- Literatures state the SCOR Model is probably the closest model to be able to measure the construction industry's performance, but fails to appreciate the project's activities that managers face during the many phases of mega-projects;

- The researcher believes the CPPM design is an improvement over the SCOR Model's 250 KPIs, to a new enriched SCOR Model (366 KPIs), which measures all activities of construction project management during mega-projects. Furthermore, the enriched model was then minimised in 5 tiers.

The researcher concludes the Construction Performance & Productivity Model (CPPM) achieves its expected comparative evaluation and a strong replacement to the SCOR Model used by most manufacturing and consultant firms. The CPPM (design) and its kernel theories (science) offer an improvement over the current literature, when attempting to measure project processes throughout all phases.

4.6.3.4. Complex and Composite Concept

Fourth, an evaluation must consider that a design science process is a "complex, composite concept", which is composed with a number of different criteria beyond simple achievement of an artifact's main purpose (Venable *et al*., 2016). Together with style, utility, quality, and efficacy, a design artifact must be rigorously demonstrated via well-executed evaluation methods (Venable *et al*., 2016). In addition, the proposed artifact can be evaluated in terms of functionality, completeness, consistency, accuracy, performance, reliability, usability, fit with the organization, and other relevant quality attributes' (Hevner *et al.*, 2004).

- The researcher understands the complexity of the construction industry and the interaction between many stakeholders. The researchers had the privilege to work, in a prolonged engagement, at a corporate level with one of the worlds' largest engineering firm over a four (4) year period and participated in the conception, feasibility and constructability of several mega-projects ($460M- $3.2B);

- From these experiences, the researcher had the opportunity to conduct a Participant Observations and analysed the project flow activity from Conceptual to Construction and Closed-Out phases;

- The researcher had also the privilege to have worked for many years (and still working today) in several remote construction sites, building mines. In one of these sites, the researcher was able to conduct an Action Research where inventory accuracies were measured amongst the two largest departments of a prime contractor;

- The researcher then went on to test an artifact through semi-structured interviews and survey with senior management. Review of literatures, constructs, work experience, Participant Observation and Action Research methodologies, interviews and survey all contributed to understand the complexity of mega-projects;

- The researcher considered when designing its Construction Performance & Productivity Model, several comments from senior tradesmen and tradeswomen, procurement and cost specialists, engineering and construction staffs' experience, planners, schedulers and other construction specialists;

- The CPPM is created with the spirit that the artifact has an organisational fit with today's construction reality;

- Finally, the CPPM's complexity was tested under four different kinds of contractual agreement (1) Time & Materials as seen by an Owner, (2) Lump Sum as seen by an Owner, (3) Time & Materials as seen by a Contractor, and (4) Lump Sum as seen by a Contractor.

The researcher concludes the CPPM took into account the challenges and the complexity facing each stakeholder during the construction mega-projects. Review of literatures, constructs, work experience, Participant Observation and Action Research methodologies, semi-structured interviews and survey all contributed to understand the complexity of mega-projects.

4.6.3.5. Undesirable Impacts

Fifth, an artifact may be evaluated for other "undesirable impacts" (Venable *et al.*, 2016), otherwise known as side effects.

- Having worked for more than twenty (20) years in the field of supply chain, the researcher understands its own subjectivity toward implementing a supply chain approach within the construction industry. However, to counteract this subjectivity, the researcher went on to conduct robustness testing with senior management staffs that participated in semi-structured interviews and a survey;

- The researcher validated the pros and cons amongst performance attributes that covered all phases and activities of construction project management. For instance, the seven (7) performance attributes selected covered the activities during the five (5) phases of project;

- Procurement reliability and responsiveness as well as the "P – field procurement" in EPCM covers the supply chain activities occurring in a project. There were also other supply chain metrics that were covered by the Level I metrics Off-Site Complexity;

- Engineering and construction management were covered under the "E" and "CM" in the performance attribute of EPCM Agility. In addition, the complexity of managing a construction site was also covered by the performance attribute of Job-Site Complexity;

- The performance attribute of Project Controls covers the financial aspect related to a project;

- Workers (Employee) Management covers the manpower, including crews and managers, primarily during the construction phase;

- The researcher offered to the interviewees more than 366 metrics which included mostly non-supply chain metrics;

- The researcher interviewed senior managers who held a wide variety of job positions at corporate and job sites;

- The survey included two (2) types of contracts (Lump Sum Contract and Time & Material Contract) amongst two different types of stakeholders (Owners and Contractors), for a total of four (4) of contracts.

In summary, the researcher, subjective to integrate (promote) supply chain processes during mega-projects, made every effort to propose a model to participants with attributes and metrics that were covering every phase of construction project management. As demonstrated in section 4.5.8, Level I, II and III that ranked 1st and 2nd Tier, were primarily engineering + construction driven. In fact, the artifact had a combined robustness of 55%. These results clearly demonstrate the engineering and construction metrics have strong influences during mega-projects, even when placed into a supply chain framework.

However, the subjectivity towards using a supply-chain approach for the framework of the CPPM remains valid, however, the researcher acknowledges a low level of limitation caused by the researcher's preferential supply chain background.

4.6.3.6. Knowledge Outcomes

Sixth and at last, evaluation can further elaborate the "knowledge outcomes" by discerning why an artifact works or not (Vaishnavi *et al*., 2004). The knowledge outcomes for the CPPM design was obtained from these elements:

1. Reviews of literature in supply chain, construction and project management, operations management, business intelligence and analytics;
2. Qualitative observations made during the Participant Observation;
3. Quantitative results obtained during the Action Research;
4. The quantitative / qualitative results obtained during the interviews and survey;
5. The merits of the construction constructs;
6. The initiative to improve the SCOR Model;
7. The elaboration of the Construction Performance & Productivity Model, as a better choice than the current SCOR Model, proposed in the literature;
8. Proposed kernel theories that are suitable to construction management;
9. The election of mid-range theories, suitable to an industry faced with global competition and survival, as well as automation and information system integration;
10. An artifact selected by conducting a series of robustness tests through semi-structured interviews and survey;
11. The CPPM brings an important contribution to the construction communities, by closing a gap in literature;
12. The CPPM challenges the integration of supply chain driven-process into mega-projects, which are commonly engineering and construction-driven;

13. The CPPM design answers three (3) important questions to knowledge contribution, set by Wilson (2002):

    - It is true there is a managerial problem and a gap in literature;

    - This thesis brings new contribution to research by introducing 366 metrics related to construction project management;

    - The design, the science and the knowledge of this thesis is interesting.

14. In addition to Wilson (2002) contribution knowledge, the researcher states its CPPM and thesis bring an important contribution to the construction communities by having answered the following questions below:

    - A supply chain integration during construction mega-projects should have a substantial interest for the construction industry;

    - Integrating supply chain processes into construction mega-projects may not solve directly the managerial problems expressed in this thesis, however, it can assist the construction industry at controlling all cost and schedule aspects of project activities, not just the ones in engineering and construction management;

    - Understanding the underlying of supply-chain processes along with other processes (engineering, construction, project controls, employee management, project complexity and integration), will make a substantial contribution toward finding a solution to the managerial problems in the construction industry;

    - The CPPM and this thesis serve to advance knowledge in solving, in part, the managerial problems (projects completed over budget and late deliveries) and offer new contribution to the construction communities.

The researcher concludes the validation of the Construction Performance & Productivity Model, based on the following statements:

- First, it achieves its expected environmental utility;

- Second, the substantiation of the artifact provide evidence that the model will be useful for solving problems or making some improvement;

- Third, the researcher also concludes the Construction Performance & Productivity Model is a strong comparative replacement to the SCOR Model;

- Fourth, the CPPM and its kernel theories makes an improvement over the current literature, and the non-necessity to measure a law or prove a theory;

- Fifth, the researcher concludes the CPPM considered the challenges and the complexity of the construction mega-projects with the assistance performance attributes and metrics covering all phases of a project;

- Sixth, the researcher also concludes the CPPM framework was in fact supply-chain biased, however, the results of using the top 1st and 2nd Tier Level I, II and III metrics for the final design clearly demonstrate the engineering and construction metrics have strong influences in mega-projects, even when placed into a supply chain framework;

- Finally, the researcher concludes the CPPM design and its thesis promote knowledge contribution to the construction communities.

4.6.4. Justification Knowledge

The fact that plurality is key to the framework of Design-Science theory, its knowledge should span across multiple genres of inquiry, requiring variety in its justification and evaluation approaches. That is said, this pluralism thinking is supported by Hart (2000), whereas differing genres of inquiry in any single study will produce knowledge in differing ways, requiring differing kinds of criteria to properly evaluate the study results. In the study of Baskerville *et al.* (2015), the authors proposed several justification knowledges that must be met in order to have a valid design-science research. The criteria for justification knowledge are met through the following items:

4.6.4.1. Prolonged Engagement

As defined by Lincoln *et al*. (1985) and stated in Baskerville *et al.* (2015), a prolonged engagement includes the investment of sufficient time to achieve research purposes including learning and testing.

- In this Design-Science Research, the researcher was able to obtain prolonged engagement after working in corporate and construction field activities starting in 2011 at major global EPCM. Then, through a Participant Observation and understanding the project flow activities over two (2) years between 2013-2014, or through an Action Research methodology for another three (3) years at a construction site (2014-2016), the researcher worked in the field or in the office long enough to develop an appreciation of mega-projects;

- The researcher spent a total of seven (7) years between office and field works. As described by Guba (1981), spending an extended period (i.e. 2011-2017) allows locals (trades union, owners, CMT, engineering firms, contractors, consultants, etc.) to adjust to the presence of the researcher and gained its confidence as an expert in the matter of study;

- The long period (2011-2017) of observation also allowed the researcher to evaluate its own developing constructs.

The researcher concludes that having spent seven (7) years in an engineering firm and construction fields in various management positions meet the criteria set by the statement of prolonged engagement.

4.6.4.2. Persistent Observations

As defined by Guba (1981) and stated in Baskerville *et al*. (2015), persistent observations are built when extended interaction with a situation or a milieu occurs, and subsequently the researcher develop an understanding of the essential characteristics or pervasive qualities. According to Lincoln et al., (1985), persistent observation adds salience to the immersion of the researcher through prolonged engagement by helping identify those characteristics and elements that are most relevant to the problems. Thus, while prolonged engagement will provide an understanding of a project scope, persistent observations, on the other hand, provide depth of understanding of the construction mega-projects' processes. The criteria of persistent observation, such as the constructs observed and enumerated in Chapter One, were observed with consistence during the phases of engineering, planning and construction. Hence, the persistent observations, or constructs for this research are stated as followed:

- Construct no.1: Diverging Objectives amongst stakeholders;
- Construct no.2: Fragmented Supply Chain Processes;
- Construct no.3: Status Quo in the Construction Industry;

- Construct no.4: Homogeneity in Mega-Project Management;
- Construct no.5: Macro-Reporting During Mega-Projects;
- Construct no.6: Changes Are Costly;
- Construct no.7: Uncertainty is Common.

The researcher noted persistent observations during the seven (7) years spent in recording constructs, taking parts in a Participation Observation and an Action Research methodology, and confirmed through semi-structured interviews and survey.

4.6.4.3. Originality

As defined by Martin (2009a), and stated in Baskerville *et al*. (2015), originality results from the willingness to experiment, spontaneity in response to a novel situation, and openness to trying something different that perhaps first planned or intended and describes that it requires openness to the process of experimentation, trial and error and iterative prototyping.

- The researcher originally used the Resource Based View (RBV) approach for its operative framework, but while writing its *DBA 970 Proposition de recherche*, the RBV was superseded by several kernels' theories. For instance, the researcher adopted a new vision on global competition and explored the Dynamic Capability Theory, the Theory of the Adoption of IT, the Co-Alignment Theory and Contingency Theory, the Structuration Theory of Duality and finally, the paradigm of the Design Science Research Theory;
- The researcher originally used the SCOR Model, but prior to conducting its semi-structured interviews and one survey with senior construction managers, the basis for the Construction Performance & Productivity Model (CPPM) was enriched as a Design-Science Research's artifact. The CPPM, as opposed to the SCOR Model, attempts to measure activities in all phases of construction project activities. Furthermore, the CPPM measured these activities with engineering and construction related performance attributes and metric levels;
- The researcher was able to spend seven (7) years in the fields and gained live experience in DSR, as opposed to laboratory simulations and proving laws or theories.

The researcher concludes the CPPM and the thesis itself fulfill the criteria of originality through an artifact, fed by live experience, interviews, survey, constructs, mid-range kernel theories and reviews of literatures.

4.6.4.4. Inventiveness

Buchanan (1992) and Baskerville *et al*. (2015) define the inventiveness of a design lies in a natural or cultivated and artful ability to return to those placements and apply them to a new situation, discovering aspects of the situation that affect the final design.

In this research, the researcher understood after long years of observation that the construction industry did not need a complicated model, nor using a model involving complicated algorithms and advanced micro-economics formula, which furthermore, have no meaning for the common construction managers or any stakeholders. The CPPM, therefore displays a level of inventiveness based on the following items:

a. At the beginning of the design, the researcher opted for the Supply Chain Operations Reference (SCOR) model, introduced by the Supply Chain Council (USA);

b. However, the SCOR model, although effective in many industries, lacks the understanding of, and analysis capabilities, for the various activities in project construction project management. Overall, the SCOR model is not efficient at measuring the construction processes. It was then enriched and minimised into the CPPM;

c. The CPPM is a design, which is based on natural settings (e.g.: live office and live construction fields);

d. The CPPM is a design that is cultivated by information based on constructs, interviews, survey and remarks made by senior managers.

e. The CPPM design (artifact) which replaces the SCOR Model, brings a better understanding of the overall attributes, metrics and processes commonly found in a construction mega-projects. For instance, the following performance attributes were changes:

- Supply Chain Reliability to Procurement Reliability;
- Supply Chain Responsiveness to Procurement Responsiveness;
- Supply Chain Agility to EPCM Agility;
- Supply Chain Costs to Project Controls;
- Supply Chain Assets Management to Workers (Employees) Management;
- Supply Chain Complexity to Project Complexity;
- Supply Chain Maturity to Project Integration.

The researcher concludes that CPPM which is proposed in this thesis, fulfills the criteria of inventiveness through the facts that the CPPM artifact is formulated based on natural settings, cultivated by great inputs from senior managers and can be most likely be exported to other construction sites.

4.6.4.5. Objectivity & Confirmability

As defined by Lincoln *et al*. (1985) and stated in Baskerville *et al.* (2015), objectivity denotes intersubjective agreement; if multiple observers can agree on a phenomenon, their collective judgment is considered objective. Guba (1981) also refined the word objectivity into the term confirmability. In accordance with Guda (1981), confirmability is the degree of neutrality of the extent to which findings of a study are shaped by the respondents and not researcher bias, motivation, or interest. Confirmability is the naturalistic equivalent to conventional evaluation criteria of objectivity (Guba (1981).

According to Lincoln et al. (1985), the question underlying the establishment of the confirmability criteria can be found by the following question: How can one establish the degree to which the findings of an inquiry stem from the characteristics of the responders and the context and not from the biases and motivations and perspective of the researcher?

For ensuring the objectivity and confirmability of this research, the findings such as the constructs and the observations (Participant Observation and Action Research) were challenged by a set of semi-structured interviews and survey, with senior managers. Their answers were analysed impartially, with no subjectivity, and the participants did dictate which performance attributes and metrics were judged as important (1st and 2nd tier), depending on the types of contract (e.g.: Lump Sum and Time & Materials) and if you were in the shoes of being owners or contractors.

Although a supply chain framework was used to design the CPPM, the final performance attributes and metrics were overwhelmingly pertaining to engineering and construction activities, thus proving (1) the subjective design into an artifact is, (2) objective in its findings, thus confirming a form of (3) confirmability.

Hence, the researcher concludes the CPPM's artifact fulfills the criteria of objectivity and confirmability through a selection of performance attributes and metrics, obtained from Level I, II, III top 1st and 2nd tier.

4.6.4.6. Reliability

As defined by Lincoln *et al*. (1985), Kerlinger (1973) and stated in Baskerville *et al.* (2015), reliability is synonymous with dependability, stability and consistency, predictability and accuracy. Reliability suggests that it is reasonable to assume that each repetition of the application of the same or equivalent instruments to the same units will yield similar measurements (Ford, 1975). According to Lincoln *et al.* (1985), since there can be no validity without reliability, (and thus no credibility without dependability), a demonstration of the former is sufficient to establish the latter. The following reliability justification are presented below: a) dependability, b) consistency, stability, predictability, and c) credibility.

4.6.4.7. Dependability

As defined by Lincoln *et al*. (1985) and stated in Baskerville *et al.* (2015), dependability is the process for showing that the findings are consistent and could be repeated. The researcher believes the results are dependable (and credible) based on the following repeatability:

- The researcher believes its thesis displays reliability, which is predetermined by validity (credibility), in terms of its prolonged engagement and persistent observations, which offer a strong level of credibility;
- In addition, the correlation between the Participant Observation, the Action Research and the results from the survey allow the researcher to validate the dependability, but only however, for the construction site where the artifact was applied to;
- The question arises where the findings were never repeated in other construction sites, other than the ones which the researcher works. One reason for the lack of repeatability, hence, the lack of dependability, was the cost and the time required to conduct another research. However, this limitation opens the door to further research in the form of exploring the performance attributes and Level I, II and III metrics that are proposed in this model.

Therefore, the researcher concludes the artifact is dependable for the construction site, where it was applied to. However, the researcher noted a limitation in stating this thesis is dependable, since the research was not repeated in other regions, or in other construction sites.

4.6.4.8. Consistency, Stability & Predictability

As defined by Guba (1981) and stated in Baskerville *et al*. (2015), consistency (along with stability and predictability) is a key concept underlying reliability. Consistency can be interpreted as a concept that embraces elements both from stability (implied by reliability) and from traceability required by explainable changes in instrumentation (Baskerville *et al*., 2015). The researcher developed an artifact where Level I, II and

III metrics were consistent to both owners and contractors in either any types of contracts (Lump Sum and Time & Materials). Table 126 demonstrates the kind of consistency which the artifact's results provide:

Table 4. 127
Final 1st & 2nd Tier Level II / III metrics in CPPM

	1st Tier All Forms of Contract	1st Tier Lump Sum Contracts	1st Tier Time & Materials Contract	2nd Tier All Forms of Contract	2nd Tier Lump Sum Contracts	2nd Tier Time & Materials Contract
Procurement Reliability		1.1			1.1	1.5
Procurement Responsiveness						
EPCM Agility	5.2, 5.8	5.1, 5.2, 5.8	5.2, 5.8	3.4, 5.1, 5.2, 5.8	3.1, 3.2, 3.3, 3.4, 5.1, 5.2, 5.8	3.4, 5.2, 5.8
Project Control			6.1, 6.2, 7.1, 7.2	6.1	6.1	6.1, 6.2, 7.1, 7.2, 7.3
Employee Management						
Project Complexity						

Dany Julien (2019)

- The metrics that were consistent to both owners and contractors during either a Lump Sum or Time & Materials contracts, when considering 1st and 2nd Tier performance were:

    - The performance attribute of EPCM Agility – Engineering with one (1) Level II/III metric - 3.4;

    - The performance attribute of EPCM Agility - Construction Management with three (3) Level II/III metrics – 5.1, 5.2, 5.8;

    - The performance attribute of Project Controls – Budget & Planning with one (1) Level II/III metric – 6.1;

- The metrics that were consistent to both owners and contractors with Lump Sum contracts only, when considering 1st and 2nd Tier performance were:

    - The performance attribute of Procurement Reliability with one (1) Level II/III metric – 1.1;

    - The performance attribute of EPCM Agility – Engineering with four (4) Level II/III metric – 3.1, 3.2, 3.3, 3.4;

    - The performance attribute of EPCM Agility - Construction Management with three (3) Level II/III metrics – 5.1, 5.2, 5.8;

    - The performance attribute of Project Controls – Budget & Planning with one (1) Level II/III metric – 6.1;

- The metrics that were consistent to both owners and contractors with Time & Materials contracts, when considering 1st and 2nd Tier performance were:

  - The performance attribute of Procurement Reliability with one (1) Level II/III metric – 1.5;

  - The performance attribute of EPCM Agility – Engineering with one (1) Level II/III metric – 3.4;

  - The performance attribute of EPCM Agility - Construction Management with two (2) Level II/III metrics – 5.2, 5.8;

  - The performance attribute of Project Controls – Budget & Planning with two (2) Level II/III metric – 6.1, 6.2;

  - The performance attribute of Project Controls – LEM Spends with three (3) Level II/III metric – 7.1, 7.2, 7.3.

Through the consistencies with certain Level II/III metrics, the researcher concludes the CPPM has achieved a certain level of consistency amongst owners and contractors, in a form of contractual agreement (Lump Sum and/or Time & Materials contracts). Moreover, the model could be further tested in other construction sites in the future, and subsequently offering a higher level of confidence and consistency to it. The researcher acknowledges a limited consistency factor for this artifact, due to the fact it wasn't tested outside.

4.6.4.9. Credibility

As defined by Lincoln *et al*. (1985) and stated in Baskerville *et al.* (2015), the credibility of a research is distinct by the amount of confidence there is in the "truth" of the findings. This research involves a naturalistic setting for the Participant Observation and the Action Research. The credibility of the findings through this naturalistic setting are validated by:

a. Its prolonged engagement;

b. Its persistent observations made between reviews of literature, constructs, the Participant Observation results, the Action Research results, the results of the interviews and survey;

c. Its originality as a model which covers all activities of construction project management;

d. Its originality and inventiveness in adopting new terminologies related to construction project management;

e. Its objectivity and confirmability;

f. Its consistency, and at last;

g. Its internal validity.

Furthermore, the artifact also meet the credibility expressed by Lincoln *et al*. (1985) and Baskerville *et al.* (2015), through the support of its validation process, the Design-Science Research's four (4) principles and the six (6) elements of the evaluation for an artifact. The reader should also note the term "credibility" is the equivalent for the conventional scientific term "internal validity" and denotes trustworthiness of the findings.

4.6.4.10.Internal Validity

Cook *et al*. (1979) define internal validity as "the approximate validity" (the best available approximation of the truth or falsity of a statement). The authors infer that a relationship between two variables is casual or that the absence of a relationship implies the absence of a cause. As defined by Lincoln *et al*. (1985) and stated in Baskerville *et al.* (2015), internal validity can be defined as the extent to which variations in the outcome (dependent variable) can be attributed to controlled variation in an independent variable.

- The credibility of this thesis is supported by the ease of access to information, which the researcher enjoyed throughout the period of its research. While employed at corporate level (Participant Observation) or at a construction site (Action Research), the researcher held managerial positions and made observations accessible at any time, over a period of seven (7) years;

- The credibility of this thesis is supported by observing constructs and finding a correlation between the Participant Observation, the Action Research and the results obtained from the interviews and survey;

- The profile of each participant is also an important factor of credibility. The participants had many years of quality construction experience, and obtaining such quality participants over such a prolonged period, is hard to get for the standard researcher;

- Remarks by the participants were recorded during the semi-structured interviews. Participants' feedback ensured that the researcher was accurately depicting the participants' experiences;

- The method of participant checking through recording remarks, and conducting triangulation are good methods to use when conducting participant observations, interviews, or survey (qualitative research), because they improve research credibility (internal validity) and potentially transferability (external validity).

4.6.4.11.Principle of Contextualization

In certain situations, competing explanations may arise. George *et al.* (2005) discusses the importance of examining alternative and perhaps even conflicting explanations. As defined by Klein *et al*. 1999) and stated in Baskerville *et al*. (2015), the principle of contextualization requires critical reflection of the social and historical background of the research setting, so that the intended audience can see how the current situation under investigation emerges. They state that the plausibility of an explanation is enhanced to the extent that alternative explanations are considered and found to be less consistent with the data, or less supported by available generalizations. Klein *et al.,* (1999) described a similar notion as dialogical reasoning, which requires sensitivity to possible contradictions between the theoretical preconceptions guiding the research design and actual findings.

- The researcher noted the first conflicting thought, was raised when keeping information about labour forces' profile and management in order to pursue performance analytics. This sort of profiling was seen by younger participants as innovative, whereas older senior managers worried about potential legal conflict in the view of "*Big Brother is Watching You"* symptom;

- The younger management states in several remarks that power of analytics must be sought in construction mega-projects, whereas the older management understood the legality of juggling with information without the consent of the crew workers as potentials litigation;

- Managing inventory (metric 4.4) appears from these survey' results as non-essential for both owners and contractors. However, the researcher would argue that even though a fixed price has been set under a Lump Sum contractual agreement, not controlling your inventory would subsequently lead to budget overruns and late scheduling in equipment and materials installation;

- When recording the remarks for the performance attribute of Project Complexity, participants viewed Project Complexity's attributes as essential throughout the project, with an understanding of the importance of conducting Off-Site Complexities analysis during the Front-End Planning; and an understanding of the Job-Site Complexities during the Detailed Engineering and highly essential during the Construction Phase. However, this score does not correlate with the Off-Site Complexity Level III metrics during the interviews and the survey;

- The Off-Site Complexity Level III metrics finished in the 5th tier, showing their non-importance by the participants taking part in interviews and participants. This is a conflicting view between pro-supply chain culture versus engineering and construction-driven cultures.

The researcher acknowledges some conflicting explanations for certain metrics; however, the researcher demonstrated several justification knowledges, making the CPPM a valid design-science research.

4.6.4.12. Conclusion – Justification Knowledge

The researcher concludes that justification knowledge was met for the following criteria:

- The researcher concludes that having spent seven (7) years in a corporate office and construction fields as a manager, meet the criteria set by the statement of prolonged engagement;

- The researcher noted persistent observations during the seven (7) years in a corporate office and construction fields as a manager, with notable constructs, participation observation and action research;

- The researcher concludes this CPPM fulfills the criteria of originality through its artifact, fed by live experience, interviews, survey, constructs and kernel theories;

- The researcher concludes that CPPM fulfills the criteria of inventiveness through the facts that the design is formulated based on natural settings, cultivated by great inputs from senior managers and can be most likely exported to other construction sites;

- The researcher concludes the CPPM design fulfills the criteria of objectivity through selecting for performance attributes and metrics empirically, after conducting interviews and survey;

- The credibility of the findings is validated by the prolonged engagement, consistent observations made during the Participant Observation and Action Research methodologies, its originality, its inventiveness, its objectivity and at last its internal validity;

- The credibility of the findings is also supported through the experience of the participants, all of them being in senior management positions. The profile of each participant is also an important factor to consider in this research. The participants had many years of quality construction experience in mega-projects. Moreover, having that kind of quality participants over such a prolonged period (7 years), is hard to get for the standard researcher;

- The credibility of this thesis is supported by observing constructs and finding a correlation between the Participant Observation, the Action Research and the results obtained from the interviews and survey;

- Furthermore, the artifact also meet the credibility expressed by Lincoln *et al*. (1985) and Baskerville *et al.* (2015), through the support of its validation process, the four (4) principles and the six (6) elements of the evaluation of an artifact prescribed in a Design-Science Research;

- The researcher acknowledges the CPPM creates some conflicting explanations for certain metrics when analyzed under different types of contract. The researcher believes that all conflicting measurement, remarks, interviews and survey were met with valid explanations;

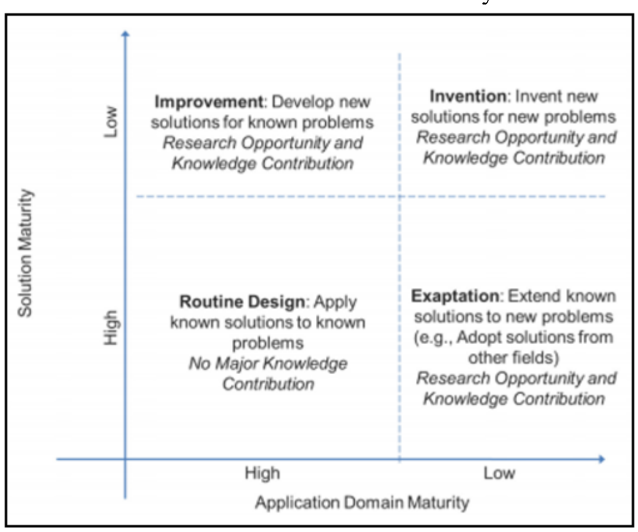
- The CPPM suits the design requirement of DSR, whereas the supportive kernels theories suit the science part of DSR.

4.6.5. Artifact Maturity

In accordance with Gregor *et al*. (2013), the contributions of this thesis toward solving the managerial problems expressed in the first chapter can be described on a maturity axle. For instance, the maturity level of any managerial problem depends on two (2) factors: a) problem maturity expressed on the x-axis and b) solution maturity which it is on the y-axis.

Using Gregor's comparative table in Figure 4.1, the Construction Performance & Productivity Model can be evaluated on the basis an artifact causing an improvement, invent a solution, is a routine design and/or export a new solution in a form of exaptation.

Figure 4. 1
Solutions vs. Problems Maturity



Gregor et al. (2013)

4.6.5.1. Improvement

The researcher believes the Construction Performance & Productivity Model is an improvement over the SCOR Model, since it measures all activities of construction project management during mega-projects, including seven performance attributes.

The CPPM is also based on a natural setting (live office and live construction fields) and cultivate its information based on reviews of literatures, constructs, interviews, survey and remarks made by senior managers.

The Construction Performance & Productivity Model is originally based on the Supply Chain Operations Reference Model, created by the Supply Chain Council in the United States. Literatures, though, state the SCOR Model is probably the closest model to be able to measure the construction industry's performance, has failed to appreciate the project's challenges and complexities that construction stakeholders face during the many phases of mega-projects.

Hence, the CPPM is by itself an improvement over the SCOR Model, which draws its deep understanding from construction project activities, starting at the Conceptual Phase and running throughout the project to the Construction (Close-out) Phase. The framework of the CPPM is integrating supply chain processes into construction project management and to create better solutions for the construction industry, such as controlling project costs and schedule delivery. The CPPM thus replaces the SCOR Model, brings a better understanding of the construction processes, provides more specific performance attributes, and metrics commonly found in a construction mega-projects. For instance, the following performance attributes were changes:

a. Supply Chain Reliability to Procurement Reliability;

b. Supply Chain Responsiveness to Procurement Responsiveness;

c. Supply Chain Agility to EPCM Agility;

d. Supply Chain Costs to Project Controls;

e. Supply Chain Assets Management to Workers Management;

f. Supply Chain Complexity to Project Complexity;

g. Supply Chain Maturity to Project Integration.

4.6.5.2. Invention

The CPPM can't be considered an invention since the researcher states that its CPPM is an improvement. An invention, as described by Gregor *et al*. (2013) is a radical breakthrough and a clear departure from the accepted way of thinking and doing. Although the CPPM reflects one of the solutions sought by *McKinsey & Co*., in which supply chain processes should be adopted in construction management, the reality today is that mega-projects are engineering-driven at the onset of the project and construction-driven during the execution. Henceforth, as much as the researcher would like to present a construction project that is supply-chain-driven, the construction culture still applies the standard ways of doing business, with some degree of improvement, such as bringing information technologies into the field, but it is not inventive by any ways.

Moreover, the CPPM could only be considered as inventive, at the time the artifact could be evaluated and re-evaluated through a set mid-range theory, tested in various mega-projects. This is not the case for this model, being a first attempt to present a constructive design, tailored for the construction industry.

4.6.5.3. Routine Design

The routine design applies known solutions to known problems, however, there is no major contribution to creating knowledge of why and how it solves the problems. In other words, routine design occurs when existing knowledge for the problem is well understood and when designs/artifacts are used to solve the problem (Gregor et al., 2013).

Since we know the construction industry has been criticized for delivering projects late and over budget for decades and not much has changed today, the construction industry's stakeholders are not obviously using any routine design, to solve the construction's managerial problems. In conclusion, the artifact proposed for this thesis is not part of a routine design which would solve immediately the managerial problematic of this thesis. However, the researcher believes, even tough the CPPM is not a routine design, that the artifact does contribute to new knowledge.

4.6.5.4. Exaptation

In terms of exaptation, the knowledge contribution is obtained when design knowledge that already exist in other fields (e.g. manufacturing), is extended or refined so that it can be used with new problems in other fields like construction. The SCOR Model which is frequently used in the manufacturing sectors would contribute toward an expectation knowledge, if only, it would be able to solve the managerial problems express in this thesis. However, as explained in the improvement contribution above, the SCOR Model, which perform well in the manufacturing sectors, has several flaws when faced with construction activities during mega-projects. Thus, the researcher had to modify the original model (SCOR) into a more suitable one (CPPM), taking into consideration the detailed activities specific to construction project management.

In conclusion, the researcher concludes the CPPM design is an improvement over the SCOR Model, since it measures all activities of construction project management during mega-projects, including seven (7) performance attributes, Level I, II and III metrics that are relevant to construction. The researcher concludes that modifying the framework of the SCOR Model into an artifact (CPPM), is an example to a semi-exaptation, where partial knowledge from the manufacturing's supply chain processes are transferred, in part, into a new derivative model (e.g. CPPM). Finally, the artifact is faced with managerial problems which are described as highly mature. Although there exist several solutions to the managerial problems in construction, which are known and readily available, the level of solution maturity is rated as low, and the problems persist today.

4.6.6. Artifact Contributions

Gregor *et al.* (2013) propose that an artifact (CPPM) must make also a contribution to the industry (e.g. construction) by improving the prescriptive knowledge at three (3) different levels, which are presented in Table 4.127.

Table 4. 128
Design-Science Research Contribution Types

Design Science Research Contribution Types		
	Contribution Types	**Example Artifacts**
More abstract, complete, and mature knowledge	Level 3. Well-developed design theory about embedded phenomena	Design theories (mid-range and grand theories)
	Level 2. Nascent design theory—knowledge as operational principles/architecture	Constructs, methods, models, design principles, technological rules.
More specific, limited, and less mature knowledge	Level 1. Situated implementation of artifact	Instantiations (software products or implemented processes)

Gregor et al. (2013)

4.6.6.1. Level One Contributions

Situated instantiations are often constructed to evaluate the level of improvement in comparison to the existing solution. For this research, after reviewing literatures in supply chain management and construction management, the researcher observed several algorithm and economic models, but concluded the SCOR Model was the best model to measure supply chain efficiencies in construction. However, the researcher, based on personal experience in mega-projects did not believe in the model could measure the specificity of construction project management, especially in Front-End Planning, Detailed Engineering and Construction.

The researcher concludes the SCOR Model does not meet Level One contribution to knowledge advancement, and subsequently, the model must be improved in order to face the complexity of construction project management.

4.6.6.2. Level Two Contributions

Understanding the SCOR Model cannot measure the performance attributes and metrics, related to construction project management, the CPPM design is proposed in this doctoral thesis, as a research improvement. For instance, SCOR Model measures approximately 250 Level III metrics in manufacturing, whereas the CPPM design offers more than 366 Level III metrics, before being minimised to 305 Level III metrics, segregated into five (5) tiers. The CPPM framework has also been reinforced with semi-structured interviews, survey, remarks, and constructs conducted amongst senior construction stakeholders. In fact, the strength of the CPPM can be broken down as followed:

a. At first, during the interviews, the CPPM contained seven (7) performance attributes, thirteen (13) Level 1 metrics, forty-nine (49) Level II metrics and 366 Level III metrics;

b. After the semi-structured interviews and survey, the CPPM was then reduced to contain six (6) performance attributes, eleven (11) Level I metrics, thirty-eight (38) Level II metrics and 1305 Level III metrics, which are segregated into five (5) tiers;

c. The final design elected the 1st and 2nd tier Level II and III metrics. The final CPPM contains three (3) performance attributes, five (5) Level I metrics, fourteen (14) Level II metrics and 130 Level III metrics. This final CPPM design targets more specifically the construction activities, as opposed to the manufacturing focus of the SCOR Model.

The researcher concludes the Construction Performance & Productivity Model achieves Level Two Contribution to knowledge advancement.

4.6.6.3. Level Three Contributions

In this last level of knowledge contribution, the evaluation of the artifact (CPPM design) leads to knowledge contributions to new descriptive knowledge in the form of expanded understanding of a theory. Due to lack of testing the proposed CPPM in other mega-projects, this thesis couldn't formulate any kind of mid-range theory at this time. Hence, the researcher concludes the CPPM design does not meet *Level Three* contribution to knowledge advancement. However, opportunities for future research exists using the CPPM design, which could potentially lead to formulating a mid-range theory and bring a further contribution to construction project management.

4.6.7. Conclusion – Artifact Validation

First, the researcher concludes the Construction Performance & Productivity Model has met the process validation of a Design-Science Research with four (4) basic phases: a) analysis, b) design, c) evaluation and d) diffusion.

Second, the researcher concludes the CPPM has met the four (4) principles pertaining to Design-Science Research, which are: a) abstraction, b) originality, c) justification and d) benefits.

Third, the researcher concludes the validation of the CPPM because it achieves its expected environmental utility, whereas the substantiation of the artifact provide evidence that it will be useful for solving problems or making some improvement. The researcher also concludes the CPPM is a strong comparative replacement to the SCOR Model. Overall, the CPPM and its kernel theories makes an improvement over the current literature in construction management, when attempting to measure project processes. The researcher concludes the CPPM considered the challenges and the complexity of the construction mega-projects with the assistance of performance attributes and metrics covering all phases of construction project management.

Fourth, the researcher also concludes the CPPM framework was design as a supply-chain approach, however, the results when using top 1st and 2nd Tier Level II/III metrics for its final CPPM design, clearly demonstrates the model remains engineering and construction-driven.

Fifth, the researcher concludes that justification knowledge to the construction communities was created with the following criteria being met:

- Prolonged engagement;
- Persistent observations;
- Originality;
- Inventiveness;
- Objectivity;
- Credibility;
- Internal validation;
- Design improvement;
- All conflicting statement from participants were met with valid explanations.

Sixth, the researcher recognizes there are some level of limitations to its artifact due to:

- The artifact is dependable for the construction site where it was only applied to, thus the researcher concludes the CPPM has achieved a level of consistency for only the construction site it was tested to it;
- The research was not repeated in other regions, or in other construction sites;
- The researcher acknowledge that consistency is a limited factor for this artifact.

Seventh, the CPPM design is by itself an improvement over the SCOR Model, which draws its deep understanding from the construction project activities, starting at the Conceptual Phase and running throughout the construction project to the Close-out Phase. Finally, the artifact is faced with managerial problems which are described as highly mature. Although there exist several solutions to the managerial problems in construction, which are known, the level of solution maturity is rated as low.

Eight and final, the researcher concludes the CPPM achieves a "*Level Two Contribution*" to knowledge advancement, due to its innovative originality and improvement factors. However, the artifact CPPM is limited by having been tested at only one construction site. However, further research using the CPPM design could potentially lead to formulating a better mid-range theory and bring a further contribution to construction project management.

4.7. LIMITATIONS

Struggle of evaluating a Design-Science Research method arises partly from the complexities of the environment under study. Literatures in Design-Science Research identify a variety of different evaluation methods (Gill *et al*., 2013; Hevner *et al* , 2004; Nunamaker *et al* , 1990/1991; March *et al*., 1995; Vaishnavi *et al*., 2004; Venable, 2006; Peffers *et al*., 2008), and provide little guidance for deciding what to evaluate, which evaluation methods to use or why, when, and how to use them to best conduct the evaluation components of a DSR project (Venable *et al*., 2016). For other authors, a Design-Science Research can appear to be a methodological hodgepodge (Baskerville *et al*., 2015; Sein *et al*. 2011) in such ways:

- Partly a practical problem case study;
- Partly an embedded ethnography;
- Partly a creative design;
- Partly situated practice;
- Partly action research;
- Partly a field experiment, and so forth.

The methodological hodgepodge expressed above by Baskerville *et al*. (2015) and Sein *et al*. (2011) be a limitation to some scholars. For instance, this thesis was evaluated and validated by using several methods:

- At the beginning of the evaluation, the researcher used the approach of Osterle *et al*. (2010), where a Design-Science Research follows an iterative process comprising our basic phases: a) analysis, b) design, c) evaluation and d) diffusion;

- Then, the researcher leaned on Baskerville *et al.,* 2015, and followed with four (4) basic evaluation principles: a) abstraction, b) originality, c) justification and d) benefit;

- This thesis also studied Venable *et al*. (2016)'s six (6) purposes of evaluations, which are: a) environmental utility, b) substantiation, c) comparative evaluation, d) complex and composite concept, e) undesirable impacts, and f) knowledge outcomes;

- Furthermore, in the study of Baskerville *et al.* (2015), the authors proposed several justification knowledges that must be met, in order to have a valid Design-Science Research. Subsequently, the researcher pursued the evaluation of the justification knowledge with the following criteria: a) prolonged engagement, b) persistent observation, c) originality, d) inventiveness, e) objectivity and confirmability, f) reliability, g) dependability, h) consistency, stability and predictability, i) credibility, j) internal validity, and k) principle of contextualization;

- Gregor *et al*. (2013) illustrated the managerial problems on two (2) axles where problem maturity was also evaluated on being either: a) improvement, b) invention, c) routine design, and d) exaptation. The research established the managerial problems of this thesis as highly mature.

It is easy to see why some scholars lean on stating that Design-Science Research lacks strict evaluation guidance, especially in the evaluation part of the research. The next section discusses the limitations of the Participants Observations, Action Research, interviews, survey and the artifact results.

4.7.1. Limitations to Participant Observation and Action Research

The researcher conducted two residencies as part of the DSR. First, when employed as a Transport & Logistics Manager, for a global engineering firm, the researcher conducted a Participant Observation over the project flow analysis. The researcher while employed as a Material Manager at a mega-project during a mine expansion also opted for conducting an Action Research over inventory inaccuracies. In both instances, the researcher acted on one side, as an employee, and on the other side, as a researcher. This dual role eased its access of gaining information on observing project activities at a corporate level and at several construction sites.

Thus, in both Participant Observation and Action Research residencies, the researcher' presence in the field may have influence the participants' behavior, knowing that notes and remarks were recorded. Hence, the researcher was aware that some participants may act differently or put up a façade, that is in accordance to what they believe the researcher was studying. Therefore, it was important for the researcher to employ rigor in the qualitative remarks obtained during the semi-structured interviews. Subsequently, to reduce the subjective influence made by the participants, the researcher acknowledged Jackson's (1983) five (5) pragmatic challenges that are likely to appear in conducting observation studies such as Participant Observation and Action Research:

4.7.1.1. Problems with Data Handling

The Project Flow Chart presented in Appendix E2 was the not the work solely of the researcher, per se. On the contrary, the creation of this chart was the effort of dozens of individuals which were involved in construction project management, while employed at one engineering firm. The researcher simply analyzed each activity of the Project Flow Chart and categorized them as being either, (1) Yes - supply chain activity, or (2) No - not a supply chain activity. The categorization was based on understanding if the activities dealt with a certain flow of materials, typical of supply chain processes. The reader must note that the researcher has more than twenty-five years of professional experience in logistics and supply chain and was able to use common-sense logic as to select the activity category.

Due to the researcher's employment as a Material Manager, Excel data were analyzed daily and made it suitable for an Action Research. Thus, the researched concludes there was no problem of data handing during either the Participant Observation or the Action Research.

4.7.1.2. Significant Time Gap

To avoid the large time gap between the occurrence of the event and the recording as data, the researcher carried a notebook, dedicated for the research and took detailed notes during the period of research. The end-product (Project Flow Chart) is a significant work amongst dozens of participants and provide an evidence that data was recorded all along the observation.

As previously stated above, Excel data for the Participant Observation and Action Research were manipulated on daily basis. Notes and tables were also recorded over the prolonged period of observation. In fact, the details found in tables, figures, and appendices are a proof the researcher was able to record data over several years, that there was no time gap between the observations and the creation of the artifact.

4.7.1.3. Lengthy Delay between Research and Writing

The researcher recognizes there was a period of three (3) years between the make-up of the Project Flow Chart and the thesis write-up, and one (1 ½) year between the final results of the Action Research and the thesis write-up, and one (1) year to write the semi-structured interviews, survey and thesis alone and then formulate the Construction Performance & Productivity Model. The lengthy period of this research was due partially to rotation (Fly In / Fly Out) and the long hours of works (72-96 hrs/week) the researcher endured while working at mega-projects and conducting its researcher in parallel.

However, all data observed in the Participant Observation, Action Research, semi-structured interviews and survey were gathered, quickly analyzed, and were kept for final copy-pasting in the thesis. In such, the researcher recognized the lengthy time and prolonged period of observations but is persistent in stating the quality of the data wasn't affected by this lengthy period of research.

4.7.1.4. Problem with Infinite Amount of Data

The Project Flow Chart recorded 423 project activities during the five (5) phases of construction project management. Each individual activity was categorized into a phase and coded (100-700) as followed:

- Construction management;
- Project management;
- Engineering;
- Business development;
- Legal;
- Procurement & subcontracts;
- Project controls & estimating;
- Quality;
- Safety;
- Labour relations;
- Business administration, accounting, finance;
- Information technology;
- Environmental, safety & health.

Similar codifications were used to analyze the inventory management of the Prime Contractor during the Action Research. In total, the researcher recorded 1234 SKUs for the Electrical & Instrumentation Department and another 1444 SKUs for the Mechanical Department. The researcher concluded the large amounts of data were well managed and handled in a good qualitatively and quantitative manner.

4.7.1.5. Participants' Subjectivities

Triangulation between reviews of literatures, semi-structured interviews, survey, field notes, technical journals and other schools of thoughts in project management were conducted where several data sources for similar events were sought, compared and analyzed. In other words, data triangulation with technical journals, theories, interviews, or other methodological triangulation was used as a form of cross-checking information for the researcher. In addition, the profile of participants was well spread amongst senior management. Age, professions, tradesmen experience, management experience, etc. were well represented amongst all group of ages.

The researcher concluded there was no independence on participants' bias since several triangulations were made in order to acquire a better appreciation of overall project activities. The results ended up into the design of an artifact that is engineering and construction drive, even though, a supply chain framework was the basis for its design.

4.7.2. Limitations to Interviews and Survey

Interviews and survey lead with questions concerning facts, with behaviour, and beliefs or attitudes that are subjective to individuals. Beliefs or attitudes are complex matters, multidimensional and form a very important target for self-report techniques line interviews and survey. However, beliefs and attitudes are relatively difficult to measured (Robson, 2002).

On one hand, interviews and survey offer great statistical results when there is a large amount of representativeness. In the case of this thesis, the researcher recognizes the limitation of its statistical significance for the results obtained due to the number of participants (less than fifty) in both interviews and survey. However, the researcher points out the limitation in number of participants is counteracted by the quality of everyone who to part in the semi-structured interviews and survey. Diversity in job positions and years of experience for each participant in construction mega-projects provided the research with a wide range of opinions, remarks, opinions and quantitative results, all pertinent to construction project management.

In conclusion, the researcher recognizes the statistical significance versus the number of participants that took part in the semi-structured interviews and survey may have been a limitation to the results. However, once again, the quality of the participants neutralizes this limitation.

4.7.3. Limitations to the Artifact

The Construction Performance & Productivity Model holds some limitations in its design. The researcher concluded the CPPM achieved a level of consistency that is dependable for only the construction site it was tested to. Therefore, the proposed artifact in this thesis offers an opportunity for future research, where the artifact could be tested in other construction sites, thus offering a higher level of confidence and subsequently, more consistency to it. Thus, the researcher acknowledges the fact that consistency is a limitation factor, related to have been tested at one construction site.

A final limitation to the researcher's semi-structured interviews and survey was the range of the Likert scale between 1 and 5. Looking back at the closeness of the results, the scale could have been expanded to 1 and 10. Nonetheless, the engineering and construction metrics would have still dominated the CPPM.

4.7.4. Conclusion - Limitations

In conclusion, the researcher concludes there was two (2) limitations during the procedures of the Participant Observation and the Action Research methodologies. First, the researcher recognizes the statistical significance and the number of participants during the semi-structured interviews and survey have been a limitation to this thesis. Second, the researcher also recognizes the interviews and survey were conducted at only one mega-project site, thus affecting the maturity of the model.

Thus, the researcher acknowledges the fact that consistency is a limitation factor, related to one construction site.

4.8. RESEARCH OPPORTUNITIES

The researcher believes that several research opportunities exist beyond this thesis. For instance:

- Qualitative and quantitative researches are needed throughout all phases of mega-projects, not just construction;
- The CPPM's maturity will improve once the model is tested at different sites;
- The engineering and construction (E&C) industry is lagging in using integrated management information systems and Business Intelligence (BI) tools. There are tremendous opportunities in using analytical tools during mega-projects, especially in analysing *Big Data*;
- The marriage of academia and industrial stakeholders must be increased, for the benefits of research and mega-projects' improvement;
- Finally, the researcher incites other researchers to test this artifact (CPPM) in other mega-projects.

4.9. ETHICS

During the period of research, the researcher acted upon several roles. First, as an employee for a global engineering and a construction management firm; second, as an observer during a Participant Observation and an Action Research, third, as an analyst while conducting semi-structured interviews and one survey, and finally, as the author of this thesis.

While working for the global engineering firm, the researcher was mentored by the Vice-President of Procurement, and employed as Transport & Logistics Manager. The researcher had the privilege to have been assigned at various mining projects worldwide and received full access to information that were pertinent to its research.

During the Action Research, the researcher was mentored by the Construction Manager of the construction management firm that was managing the mill upgrade project.

During the same period of research, the researcher made no secret of its research endeavor and made it known that promoting a supply chain approach in construction was its evangelistic objective. As with any form of research which deals with human subjects, the researcher made sure the ethical boundaries were never crossed by those participating in the Participant Observation and the Action Research methodologies, or even during the semi-structured interviews and the survey.

In addition, the participants were also given a verbal description of the intents and objectives of the research being carried out. The researcher left no cause for concerns from an ethical perspective and deontological issues such as right to privacy and the right to respect. It is important to note that at no time the researcher employed any types of covert observations during the Participant Observation nor during the Action Research methodologies. In fact, the researcher having grown in a construction family, understood that working covertly in a construction environment can be dangerous as unions see the covert approach as an agent provocateur toward their members. Moreover, the use of covert participant observation in management research has historically raised serious epistemological and methodological questions (Oliver *et* al., 2008).

During the interviews and survey, the researcher clearly established boundaries before the onset of the questioning. The researcher provided guidelines with a Letter of Invitation (see Appendix H) and a Letter of Information and Consent Form (Appendix I). Participants taking parts in the interviews and the survey were all consensual and answered the interviews and survey on a voluntary basis.

The researcher regrettably received back just a few consent forms, even after reminding the participants at the end of the interviews to send them. Then, between the period of the interviews and the survey, the researcher sent another email, reminding them to complete and signed the consent. The names of the engineering and construction management firms, as well as contractors' companies' names were kept anonymous in this thesis. Similarly, names of participants in the interviews and survey were also kept anonymous. In fact, the researcher gave its outmost effort to hide name of participants and companies during the period of Participant Observation and Action Research.

In conclusion, the ethical strategies for this research established (1) clear goals with a commitment to personal values and privacies, (2) contextually focused with a Letter of Information and Consent Form, (3) freely used working documents as part of the research, (4) participated passively and actively in the daily meetings, and (5) followed specific process principals during the Participant Observations and Action Research. The confidentiality of the interviews and survey will be maintained in a sense that no participant or company name will appear in this thesis. All documents including the interviews and survey, including the notes and remarks from participants will be boxed in, in a secure place, not to be destructed for at least five years. Interestingly, several participants demonstrated a keen interest in seeing the results obtained for the final artifact. Hence, the researcher is committed to send them a synopsis of the research to the participants.

FIFTH CHAPTER
DISCUSSION

The construction industry is notorious for cost and schedule overruns. While many construction stakeholders acknowledge the potential of new management information system technologies or implementing new way of controlling processes and costs, construction stakeholders, in general, will hesitate to implement new applications, if they are considered unproven and non-tested. Simply stated by one participant during the semi-structured interviews, construction mega-projects are not laboratory fields for the academics. Construction managers have a mandate to execute a specific scope of work, not to conduct modelling nor implement software.

A review of literature covering supply chain processes in manufacturing was noted as abundant, while the same topic in engineering and construction journals, is practically inexistent. Furthermore, the review of literatures doesn't provide holistic model, nor any solid-proof framework, nor theories that measure performance and productivity with any constant results. Additionally, the researcher did not come across any model that was able to measure performance and productivity in each phase of construction project management, starting at the Conceptual Phase, followed by the Front-End Planning and Detailed Engineering Phases, and finally, ending at the Construction Phase.

One solution proposed in this thesis is the formulation of an artifact (design, model), with a supply chain framework as a base, developed through a Design-Science Research approach. Thus, after reviewing literatures and developing constructs, and through a series of observations, participations, action research, survey and semi-structured interviews, as well as applying several kernels theories, the researcher developed its artifact, titled the Construction Performance & Productivity Model.

This artifact model is assumed to be one of many potentials solutions that may help solving the managerial problems of cost overruns and late deliveries during mega-projects. The artifact contains performance attributes and metrics pertinent to all activities of construction project management. The functionalities covered in this artifact are procurement, engineering, construction, cost controls, workers (employees) management as well as project complexity and project integration.

The research evolved over seven (7) years with the freedom of adopting various methodologies and theories in order to steer with one vision: While facing rapid competition due to global market, can the researcher develop a performance and productivity model that would control projects' costs overrun and late delivery schedules, and subsequently make the Canadian construction industry more competitive worldwide?

The researcher adopted several kernel theories, which make up the composition of the Design Theories. For examples, the following kernel theories were reviewed in order presented herein within: a) Resources-Based View, b) Dynamic Capability Theory, c) Theory of Adoption of IT, d) Co-Alignment Theory, e) Contingency Theory, and f) Structuration Theory of Duality.

As Boudain (1991) explained, the formulation of these kernel theories into mid-range theories, are temporary and not final. As described before, the artifact is limited to one construction site, hence, the artifact can be considered temporary for now. For this reason, the researcher hopes that in the future, the abstract will be used in other projects, where some theories will be added or removed, in order to better understand the managerial problems during mega-projects. Henceforward, until the time a universal law in construction management is formulated, social science should avoid trying to create a universal theory for the managerial problems express in this thesis, and the use of kernel theories should be favored in the field of construction management.

The value of the Construction Performance & Productivity Model is validated by three (3) performance attributes, which included the top metrics within the 1st and 2nd tier of the Level I, II and III metrics. These metrics were tested for their level of performance and productivity robustness, including the four (4) types of construction contracts viewed by owners and contractors. The CPPM also offers 3rd, 4th and 5th Tier option. The following results below indicated the top 1st and 2nd tier:

- From the results of the semi-structured interviews and survey, the Level I metrics that performed best in the artifact were found to be the performance attributes of EPCM Agility (40%), Project Controls (40%) and Procurement Reliability (20%);
- From the results of the semi-structured interviews and survey, the Level II metrics that performed best in the artifact were found to be the performance attributes of EPCM Agility (56%), Project Controls (31%) and Procurement Reliability (13%);
- From the results of the semi-structured interviews and survey, the Level III metrics that performed best in the artifact were found to be the performance attributes of EPCM Agility (68%), Project Controls (15%) and Procurement Reliability (17%).

The combined strength of for the performance attributes, including their Level I, II, III provided the following results:

- Procurement Reliability: 16%;
- EPCM Agility: 55%;
- Project Control: 29%.

Next, although the researcher intentionally designed the artifact with a supply chain framework, the metrics belonging to engineering and construction attributes dominated the design with 40%, 56% and 68% robustness for Level I, II and III metrics respectively. The results above are indicated in Table 4.125.

Overall, the Construction Performance & Productivity Model illustrated strengths and limitations. The performance attributes and metrics display in the CPPM design covered and measured all five (5) phases of the construction project management, depending on the tier performance that is selected.

In terms of validation, the CPPM also met the four (4) principles pertaining to Design-Science Research, which are abstraction, originality, justifications and benefits. The researcher also concluded the validation of the Construction Performance & Productivity Model, because it achieved its expected environmental utility, whereas the substantiation of the artifact provided evidence that it can be useful for solving problems or making some improvement. The researcher also concluded the Construction Performance & Productivity Model is a strong comparative replacement to the SCOR Model, which fails in measuring the two (2) most dynamic and costly phases of construction project management: Detailed Engineering and Construction.

The researcher also concluded that even though the CPPM framework was, in fact, designed with a supply-chain approach, the results clearly demonstrated that engineering and construction metrics had the strongest robustness effect during mega-projects.

The credibility of the findings was also validated by its prolonged engagement, persistent observations made through its Participant Observation and Action Research methodologies, its originality, its inventiveness, its objectivity, and at last, its internal validity. Finally, the researcher concluded the CPPM design and its thesis promoted knowledge contribution to the construction communities, based on the review of literature, its prolonged engagement, persistent observations, and the criteria of originality, inventiveness and objectivity. Thus, the researcher recognizes the CPPM design has some level of limitations. The researcher concluded the artifact is dependable for the construction site where it was applied to, since the research was not repeated in other regions, or in any other sites. Therefore, the researcher concluded the CPPM has achieved a level of consistency for only the construction site it was tested to it.

SIXTH CHAPTER
CONCLUSION

Construction mega-projects are more than just being an empirical or rational testing laboratory. Algorithm models, for instance, don't apply for mega-projects. In fact, mega-projects typically involve hundreds or thousands of workers and staffs which are drawn objectively like in social science. Hence, relativism, constructivism and subjectivism of the social science are as important as rationalism, positivism and the objectivity of the natural science.

At first, the researcher reviewed literatures and attempted to measure construction activities with the application of the SCOR Model. Evidently, the researcher found out the SCOR Model was not suitable to meet the complexities and dynamic events occurring throughout the phases of mega-projects, especially during the Detailed Engineering and Construction Phases. Thus, the SCOR Model was first, enriched, then minimised with new performance attributes and metrics related to construction mega-projects. Finally, the researcher adopted the Design-Science Research approach and produced the final artifact titled Construction Performance & Productivity Model (CPPM).

Design-Science Research (DSR) espouses academic freedom in science and for real-life environment (Vendable *et al.*, 2016). The researcher rejected the philosophy of relying on one (1) holistic theory, but rather leaned toward a series of kernel theories that were related to the engineering, procurement and construction activities. Hence, this research recognizes its knowledge contributions to both design (artifact) and science (kernel theories); thus making the Design-Science Research the right approach for facing today's managerial problems in construction mega-projects.

The research's objectives were met through various research methodologies: reviews of literature, residencies and observations (participant observation, action-research, semi-structure interviews and one survey. The model provides real-time measurement at a construction site and assists in forecasting projects' costs and delivery schedule, while taking for account the four (4) types of construction contracts viewed in their own ways by owners or contractors.

One of the objectives in offering a model that is friendly to use to construction stakeholders was also met with this research's artifact (Construction Performance & Productivity Model). The users can select from a pool of various tiers (1^{st},2^{nd}, 3^{rd}, 4^{th}, 5^{th}), and various Level II/III metrics for measurement.

The researcher also believes the thesis' artifact (CCPM) fills the literature gap in construction project management, by offering a model that covers all five (5) phases of construction mega-projects. While opting for a supply chain framework, the most dominant performance attributes and metrics, considering the four (4) types of construction contracts, were metrics driven by engineering and construction activities.

Through observations recorded during a Participant Observation, an Action Research, semi-structured interviews and one survey, the researcher believes this doctoral thesis has permitted the construction management science to progress with a new model that takes for account all activities of construction project management, through a series of observations such as:

- The research identified seven (7) constructs related to construction project management, which are supported by prolonged period of observations during two residencies: Participant Observation and Action Research; and as well as a series of interviews and one survey;

- The model is supported by a Participant Observation methodology, which provided a true picture of the project activities prior and during construction. The Project Flow Chart recorded low (27%) supply chain activities during the phases of construction project management;

- The model is supported by an Action Research methodology, which provided a true picture of the construction activities. This Action Research with the Prime Contractor's three (3) departments demonstrated also very poor performance in material management with high level of inaccuracies (15-83%) during a project upgrade;

- The model's metrics covers all phases of construction project management, starting at the Conceptual Phase, followed by the Front-End Planning, Detailed Engineering, and Construction/Closed-Out Phase;

- The model that was validated through a series of principles, processes, evaluation, contribution and justification knowledge, in accordance with DSR;

- The model's originality and inventiveness, is different from the ones found in construction literature (e.g. SCOR Model);

- The model displays the artful ability to adapt to new theories, if required to;

- The model has been enriched, modified and minimised in order to be user-friendly to projects' stakeholders. Hence, the thesis' model is an improvement over the SCOR Model;

- The model's users have access to several options (1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} tiers), which reflect the amount of performance attributes and metrics to be measured;

- The model reacts differently to the types of contract in place; and

- Even though the model is based on a supply chain framework, the dominant metrics belong to engineering and construction activities.

Finally, the researcher concludes the Construction Performance & Productivity Model has achieved a level of consistency and maturity for only the construction site it was tested to. Hence, the researcher acknowledges that consistency and maturity are limitation factors for this artifact. Understanding the model's limitations, this research offer opportunities for other scientists to further test the model's validity at different construction sites, offering new potential mid-range theories, and a higher level of confidence and consistency over time.

LIST OF REFERENCES

Ajzen, I. (1991). The Theory of Planned Behavior. *Organization Behavior and Human Decision Processes.* Academic Press, Inc. 179-211; in Lai, P.C. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*, 14(1), 21-38.

Akinci, B.; Kizitas. S.; Egen, E.; Karaesme, Z. et Kecell, F. (2006). Modeling and Analyzing the Impact of Technology on Data Capture and Transfer Processes at Construction Sites: A Case Study. *Journal of Construction Engineering and Management,* 132 (11), 1148-1157.

Akintoye, A., McIntosh, G. et Fitzgerald, E. (2000). A Survey of Supply Chain Collaboration and Management in the UK's Construction Industry. *European Journal of Purchasing and Supply Chain Management,* 6(3-4), 159-168.

Akinson, P. (1990). The Ethnographic Imagination, Routledge, London, in Oliver, J. *et* Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Akyuz, G.A. et Erkan, T.E. (2010). Supply Chain Performance Measurement: A Literature Review. International Journal of Production Research, 48(17), 5137-5155.

Ala-Risku, T. et Karkkainen, M. (2006). Material Delivery Problems in Construction Projects: A Possible Solution. *International Journal of Production Economics*, 104, 19-29.

Alderman, N., Ivory, C., McLoughlin, I. et Vaughan, R. (2005). Sense-Making as a Process within Complex Service-Led Projects. *International Journal of Project Management*, 23(5), 380-385.

Allport, G. W. (1962). The General and the Unique in Psychological Science. *Journal of Personality,* 30 (3), 405-422; in Baskerville, R.L., Kaul, M. *et* Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

AlSehaimi, A., Koskela, L. et Tzortzopoulos, P. (2013). Need for Alternative Research Approaches in Construction Management: Case of Delay Studies. *Journal of Management in Engineering*, 29(4), 407-413.

Agarwal, R., Chandrasekaran, S. et Sridhar, M. (2016). Imagining Construction's Digital Future. White Paper: McKinsey & Company. www.mckinsey.com/capital-projects-and-infrastructure/our-insights/imagining construction's digital future. June 2016.

Angeles, R. (2005). RFID Technologies: Supply Chain Applications and Implementation Issues. *Information Systems Management*, 22(1), 51-65.

Asad, S., Fuller, P., Pan, W. et Daity, A.R.J. (2005). Learning to Innovate in Construction: A Case Study in Khosrowshahi, F. ARCOM, London. 2, 1215-1224.

Astley, W.G. et Van de Ven, A.H. (1983). Central Perspectives and Debates in Organization Theory. Administrative Science Quarterly, 28(4), 245-273; in Gallear, D.A., Ghobadian, A., Li, Y., O'Regan, N., Childerhouse, P. et Naim, M. (2013). An Environmental Uncertainty-Based Diagnostic Reference Tool for Evaluating the Performance of Supply Chain Value Streams. *Production Planning & Control*, 25(13-14), 1182-1197.

Atkinson, P., Coffey, A., Delamont, S. Lofland, J. et Lofland, L. (2001). Editorial Introduction, Handbook of Ethnography, Sage, London, 1-7; in Shipton, C., Hughes, W. *et* Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Azhar, S., Ahmad, I. et Sein, M.K. (2010). Action Research as a Proactive Research Method for Construction Engineering and Management. *Journal of Construction Engineering & Management*, 136(1), 87-93.

Baars, H. et Kemper, H.-G. (2008). Management Support with Structured and Unstructured Data. An Integrated Business Intelligence Framework. *Information Systems Management*, 25(2),132; in Foley, E. et Guillemette, M.G. (2010). What is Business Intelligence? *International Journal of Business Intelligence Research,* 1(4), 1-28.

Baarts, C. (2009). Collective Individualism: The Informal and Emergent Dynamics of Practicing Safety in a High-Risk Work Environment. *Construction Management and Economics,* 27(10), 949-957.

Ballard, R. 2010. Construction Logistics: A Personal View. *Logistics & Transport Focus*, 12(4), 42-45.

Ballou, R., Gilbert, S. et Mukherjee, A. (2000). New Managerial Challenges from Supply Chain Opportunities. *IEEE Engineering Management Review*, Third Quarter, 7-17; in Gulledge, T. et Chavusholu, T. (2008). *Industrial Management & Data Systems*, 108(6), 750-774.

Baker, V., Coltman, T. Fosso Wamba, S. et Keating B. (2009). Unpacking the RFID Investment Decision. *Proceeding of the IEEE*, Special Paper.

Barney, J. B. (1986a). Types of Competition and the Theory of Strategy: Toward an Integrative Framework. *Academy of Management Review*, 11, 791-800.

Barney, J.B. (1986b). Strategic Factor Markets: Expectations, Luck, and Business Strategy. *Management Science*, 32(1) 1231-1241.

Barney, J.B. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management.* 17(1), 99-120.

Barney, J.B. (1994). Competitive Advantage from Organisational Analysis. Texas A&M University, College Station, TX; in Matta, F.J., Fuerst, W.L. et Barney, J.B. (1995). Information Technology and Sustained Competitive Advantage: A Resource-Based Analysis. *MIS Quarterly*, 19(4), 487-494.

Barreto, I. (2010). Dynamic Capabilities: A Review of Past Research and an Agenda for the Future. *Journal of Management*, 36(1), 256-280.

Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Baskerville, R.L. et Meyers, M.D. (2004). Special Issue on Action Research in Information Systems: Making IS Research Relevant to Practice. *MIS Quarterly*, 28(3), 329-335.

Beamon, B. (1999). Measuring Supply Chain Performance. *International Journal of Operations and production Management*, 19(3-4), 275-292.

Baskerville, R. L. et Myers, M. D. (2015). Design Ethnography in Information Systems. *Information System Journal*, 25(1), 23-46.

Baskerville, R., Pries-Heje, J. et Venable, J. (2007). Soft Science Research: Extending the Boundaries of Evaluation in the Design Science Research. 2nd Conference on Design Science Research in Information System, in Venable, J.; Pries-Heje, J. et Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information System*, 25(1), 77-89.

Baskerville, R. L. et Wood-Harper, A. T. (1998). Diversity in Information Systems Action Research Methods. *European Journal of Information Systems,* 7(2), 90-107.

Beath, C.M. (1991). Supporting the Information Technology Champion. MIS Quarterly, 15(3), 355-371; in Lee, C.-P. et Shim, J.P. (2007). An Exploratory Study of Radio Frequency Identification (RFID) Adoption in the Healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Behzadan, A.H., Aziz, Z. Anumba, C.J. et Kamat, V.R. (2008). Ubiquitous Location Tracking for on Text-Specific Information Delivery on Construction Sites. *Automation in Construction*, 17, 737-748; in Sardroud, J.M.; Limbachiya, M.C. *et* Saremi, A.A. (2009). Ubiquitous Tracking and Locating of Construction Resource Using GIS and RFID, 1-10.

Bell, L.C. et Stukhart, G. (1987). Costs and Benefits of Materials Management Systems. *Journal of Construction Engineering,* 113(2), 222-234.

Benton, W.C. et McHenry, L. (2010). *Construction Purchasing & Supply Chain Management.* McGraw Hill, NY.

Bolstorff, P. et Rosenbaum, R. (2012). Supply Chain Excellence. *A Handbook for Dramatic Improvement Using the SCOR Model*: *Adapted for use with SAP and Global Project.* 3rd ed., AMA, New York, NY.

Boudon, Raymond (1991). "What Middle-Range Theories Are?", Capture 1 May 2018, from https://en.wikipedia.org/wiki/Action_research

Bresnen, M. (2009). Living the Dream? Understanding Partnering as Emergent Practice. *Construction Management and Economics*, 27(10), 923-933.

Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues,* 8(2), 5-21, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Buckley, R.C. (1993). How Accurate Are Environmental Impact Predictions? *Ambio*, 20(1), 3–4.

Bunduchi, R. et Smart, A. (2010). Process Innovation Costs in Supply Networks: A Synthesis. *International Journal of Management Review*, in Smart, A.Y, Bunduchi, R. et Gerst, M. (2010). The Costs of Adoption of RFID Technologies in Supply Networks. *International Journal of Operations & Production Management*. 30(4), 423-447.

Bullock, A., Stallybrass, O., Trombley, S. et Eadie, B. (1988). *The Fontana Dictionary of Modern Thought, 2nd ed.*, London: Fontana Press, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Burati, L.J., Farrington, J.J. et Ledbetter, W.B. (1992). Cause of Quality Deviation in Design and Construction. *Journal of Construction Engineering and Management*, 118(1), 34-49.

Bygballe, L.E., Jahre, M. et Sward, A. (2010). Partnering Relationships in Construction: A Literature Review. *Journal of Purchasing and Supply Chain Management*, 16(4), 239-253.

Canon, A.R. et Reyes, P.M. (2008). RFID in the Contemporary Supply Chain: Multiple Perspectives on its Benefits and Risks. *International Journal of Operations & Production Management*, 28(5), 433-454.

Carr, N.G. (2003). It Doesn't Matter, *Harvard Business Review*, 81(5), 41-49.

Carr, D.K. et Hard, K.J. (1996). Managing the Change Process. McGraw-Hill, New York; in Lee, C.-P. et Shim, J.P. (2007). An Exploratory Study of Radio Frequency Identification (RFID) Adoption in the Healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Carroll, J. et Kellogg, W. (1989). Artifact as Theory Nexus: Hermeneutics Meets Theory Based Design. *Proceedings of CHI '89,* ACM Press; in Kuechler, B. et Vaishnavi, V. (2008). Theory Development in Design Science Research: Anatomy of a Research Project. *Proceeding of the 3rd International Conference on Design Science Research in Information System and Technology*, May 7-9, Atlanta, GA.

Castanias, R.P. et Helfat, C.E. (1991). Managerial Resources and Rents. *Journal of Management*, 17(1), 155-171.

Chae, B. (2009). Developing Key Performance Indicators for Supply Chain: An Industry Perspective. *Supply Chain Management: An International Journal*, 14(6), 422-428.

Chae, M.J.; Yun, S.; Han, S.H. et Kwon, S.W. (2010). A Case Study for Integrating Lean Six-Sigma and RFID Applications in Construction Processes through Simulation Approach. *Construction Research Congress*, 246-256.

Chan, H.K. et Kumar, V. (2014). Special Issue – Applications of Reference Models for Supply-Chain Integration. *Production Planning & Control*, 25:13-14, 1059-1064.

Chan, A.P. et Yeong, C.M. (1995). A Comparison of Strategies for Reducing Variations. *Construction Management and Economics*, 13(6), 467-473.

Chan, W.P. et Raisanen, C. (2009). Informality and Emergence in Construction. *Construction Management and Economics*, 27(10), 907-912.

Chau, P.Y.K. et Hu, P.J. (2002). Examining a Model of Information Technology Acceptance by Individual Professionals: An Exploratory Study. *Journal of Management Information Systems*, 18(4), 191-229.

Changali, S., Mohammad, A. et Van Nieuwland, M. (2015). The Construction Productivity Imperative. White Paper: McKinsey & Company. www.mckinsey.com/capital-projects-and-infrastructure/our-insights/the construction productivity imperative. July 2015.

Chen, H., Chiang, R.H. et Storey, V. (2012). Business Intelligence and Analytics: From Big Data to Big Impact. *MIS Quarterly*, 36(4), 1165-1188.

Cheng, J.C.P., Law, H., Bjornsson, H. Jones, A. et Sriram, R.D. (2010). Modeling and Monitoring of Construction Supply Chains. *Advanced Engineering Informatics*, 24(4), 435-455.

Chin, S.; Yoon, S.; Kim, Y.-S.; Ryu, J. Choi, C. et Cho, C.-Y. (2005). Real-time 4D CAD + RFID for Project Progress Management. *Construction Research Congress,* 1-10.

Choo, H.J.; Tommelein, I.D.; Ballard, G. et Zabelle, T. (1999). Workplan: Constraint-Based Data Base for Work Package Scheduling. *Journal of Construction Engineering and Management*, 125(3), 151-159.

Chopra, S. et Meindl, P. (2007). *Supply Chain Management: Strategy, Planning & Operation*. 2nd ed., NJ, Pearson Prentice Hall, 371.

Chopra, S. et Meindl, P. (2007). Supply Chain Management: Strategy, Planning & Operation. 3rd ed., NJ, Pearson Prentice Hall; in Chan, H.K. et Kumar, V. (2014). Special Issue – Applications of Reference Models for Supply-Chain Integration. *Production Planning & Control*, 25(13-14), 1059-1064.

Chorn, N.H. (1991). The Alignment Theory. *Management Decision*, 29(1), 15-20.

Christopher, M. et Lee, H. (2004). Mitigating Supply Chain Risk Through Improved Confidence. *International Journal of Physical Distribution and Logistics Management*, 34(5), 388-396.

Chuang, M.L. et Shaw, W.H. (2008). An Empirical Study of Enterprise Resource Management Systems Implementation: From ERP to RFID. *Business Process Management Journal*. 14(95), 675-693.

Cicmil, S. Williams, T., Thomas, J. et Hodgson, D. (2006). Rethinking Project Management: Researching the Actuality of Projects. *Journal of Project Management*, 24(8), 675-686.

Clifford, J. (1986). Introduction: Partial Truth in Writing Culture: The Poetics and Politics of Ethnography, *University of California Press*, London, 1-26; in Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Construction Industry Institute (2008). Leverage Technology to Improve Construction Productivity. University of Texas; in Young et al 2011 Young, D.A.; Hass, C.T., Goodrum, P. et Caldas, C. (2011). Improving Construction Supply Networking Visibility by Using Automated Materials Locating and Tracking Technology. *Journal of Construction Engineering and Management*, 137, 976-984.

Construction Industry Institute II Products and Academic Applicability (White Paper). Construction Industry Institute, 2011.

Cohen, S. et Roussel, J. (2005). Strategic Supply Chain Management. New York: McGraw-Hill; in Thunberg, M. et Persson, F. (2013). Using the SCOR Model's Performance Measurements to Improve Construction Logistics. *Production Planning & Control*, 25(13-14), 1065-1078.

Cook, T. D. et Campbell, D. T. (1979). *Quasi-Experimentation: Design & Analysis Issues for Field Settings*. Boston: Houghton Mifflin Co., in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Cool, K. et Schendal, D. (1988). Performance Differences Among Strategic Groups. *Strategic Management Journal*, 9, p. 207-233; in Reed, R. et De Fillippi, R.J. (1990). Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage. *The Academy of Management Review*, 15 (1), 88-102.

Cox, A. et Ireland, P. (2002). Managing Construction Supply Chains: The Common Sense Approach. Engineering Construction & Architectural Management, 9(5-6), 409-418.

Craighead, C.W. et Shaw, N.G. (2003). E-Commerce Value Creation and Destruction: A Resource Based Supply Chain Perspective. *The Data Base for Advances in Information Systems*, 34(2), 39-49.

Cross, N. (2001). Designerly Ways of Knowing: Design Discipline vs. Design Science. *Design Issues,* 17(3), 49-55.

Crum, M. Premkumar, G. et Ramamurthy, K. (1996). An Assessment of Motor Carrier Adoption: Use and Satisfaction with EDI. Transportation Journal, 35(4), 44-57; in Lee, C.-P. et Shim, J.P. (2007). An Exploratory Study of Radio Frequency Identification (RFID) Adoption in the healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Curtin, J.; Kauffman, R. et Riggins, F.J. (2007). Making the Most of RFID Technology: A Research Agenda for the Study of the Adoption, Usage and Impact of RFID. *Information Technology Management*, 8(2), 87-110.

Daft, R.L. et Weick, K.E. (1984). Toward a Model of Organisations as Interpretative System. *Academy of Management Review*. 9, 284-295; in Keller, R.T. (1994). Technology-Information Processing Fit and the Performance of R&D Project Groups: A Test of Contingency Theory. *Academy of Management Journal*, 37(1), 167-178.

Dainty, A.R.J., Briscoe, G.H. et Millet, S.J. (2001). New Perspectives on Construction Supply Chain Integration. *Supply Chain Management: An international Journal*, 6 (4), 163-173.

Daniel, E.M. et White, A. (2005). The Future of Inter-Organizational System Linkages: Findings of an International Delphi Study. *European Journal of Information Systems*, 14(2), 188-203.

Danilovic, M. et Leisner, P. (2007). Analyzing Core Competence and Core Products for Developing Agile and Adaptable Corporation. *9th international Design Structure Matrix Conference DSM*. October 2007.

Davenport, T. et Short, J. (1990). The New Industrial Engineering Information Technology and Business Process Redesign. *MIT Sloan Management Review*. 31(4), 11-27.

Davenport, T.H. et Harris, J.G. (2007). *Competing on Analytics: The New Science of Winning.* Harvard Business School Publishing Corporation, Boston, MA.

Davenport, T.H., Harris, J.G. et Morison, R. (2010). *Analytics at Work: Smarter Decisions, Better Results*. Harvard Business Press. Boston, MA.

Davis, F. D. et V. Venkatesh. (1996). A Critical Assessment of Potential Measurement Biases in the Technology Acceptance Model: Three Experiments. *International Journal of Human-Computer Study*, 45, 19-45; in Lai, P.C. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*, 14(1), 21-38.

Davis, F. D. Bogozzi, R., P. et Warshaw, P., R. (1989). User Acceptance of Computer Technology: A comparison of Two Theoretical Models. *Management Science*, 35, 982-1003.

Delen, D, Hardgrave, B.C. et Sharda, R. (2007). RFID for Better Supply Chain Management Through Enhanced Information Visibility. *Production Operational Management*, 16 (5), 613-624.

Denscombe M. (2010). *Good Research Guide: For Small-Scale Social Research Projects.* Capture 1 December 2018, from https://en.wikipedia.org/wiki /Participant _observation

Denzin, N.K. et Lincoln, Y.S. (2005). Strategies of Qualitative Inquiry. *Handbook of Qualitative Research*, 2nd ed., Sage, Thousand Oaks, CA, in Oliver, J. et Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation In Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Desanctis, G. et Poole, M. S. (1994). Capturing the Complexity in Advanced Technology Use: Adaptive Structuration Theory. *Organization Science, 5*(2), 121-147.

DeWalt, K. M., DeWalt, B. R., & Wayland, C. B. (1998). *Participant Observation*. Capture 1 December 2018, from https://en.wikipedia.org/wiki/Participant _observation

Dierickx, I. et Cool, K. (1989). Asset Stock Accumulation and Sustainability of Competitive Advantage. *Management Science*, 35, 1504-1511.

Dutta, A.; Lee, H.L. et Whang, S. (2007). RFID and Operational Management Technology, Value and Incentives. *Production and Operations Management*, 16(5), 646-655.

Egan, J. (1998). Rethinking Construction. London, Department of the Environment, Transport and the Regions; in Thunberg, M. et Persson, F. (2013). Using the SCOR Model's Performance Measurements to Improve Construction Logistics. *Production Planning & Control*, 25(13), 1065-1078.

Ellram, L.M. (1996). The Use of Case Study Method in Logistics Research. *Journal of Business Logistics*. 17(2), 93-138.

Eisemhardt, K.M. et Martin, J.A. (2000). Dynamic Capabilities: What Are They? Strategic Management Journal, 22, 1105-1121; in Barreto, I. (2010). Dynamic Capabilities: A Review of Past Research and an Agenda for the Future. *Journal of Management*, 36(1), 256-280.

Ergen, E.; Demiralp, G. et Guven, G. (2011). Determining the Benefits of an RFID-Based System for Tracking Prefabricated Components in a Supply Chain. *Computing in Civil Engineering,* 291-298.

Feder, B.J. (2003). *Wal-Mart plan could cost suppliers millions*. Capture November 10, 2016, de http://www.nytimes.com/2003/11/10/technology/10radio.html

Fellow, R. (2010). New Research Paradigms in the Built Environment. *Construction Innovation: Information Process and Management*, 10(1), 5-13.

Fernie, S. et Thorpe, A. (2007). Exploring Change in Construction: Supply Chain Management. *Engineering, Construction and Architectural Management*, 14(4), 319-333.

Fishbein, M. et Ajzen, I. (1975). Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research. Reading, Mass; Don Mills, Ontario: Addison-Wesley Pub. Co; in Lai, P.C. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*. 14(1), 21-38.

Fleisher, G.S. et Bensoussan, B.E. (2015). *Business and Competitive Analysis*. 2nd ed. Pearson Education, Newark, NJ.

Fry, L.W. et Smith, D.A. (1987). Congruence, Contingencies, and Theory Building. *Academy of Management Review*, 12, 117-132; in Barreto, I. (2010). Dynamic Capabilities: A Review of Past Research and an Agenda for the Future. *Journal of Management*; 36(1), 256-280.

Foley, E. et Guillemette, M.G. (2010). What is Business Intelligence? *International Journal of Business Intelligence Research,* 1(4), 1-28.

Ford, J. 1975. *Paradigms and Fairy Tales: An Introduction to the Science of Meanings*, Boston: Routledge & Kegan Paul, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Fosso Wamba, S. et Bendavid, Y. (2010). Bridging the Gap between RFID/EPC Concepts, technological Requirements and supply chain e-business processes. *Journal of Theoretical and Applied Electronic Commerce Research*, 5(3), 1-16.

Fosso Wamba, S. et Chatfield, A.T. (2009). A Contingency Model for Creating Value from RFID Supply Chain Network Projects in Logistics and Manufacturing Environments. *European Journal of Information System*, 18(6), 615-636.

Fosso Wamba, S., Keating, B., Coltman, T. et Katina, M. (2009). *RFID Adoption Issues: Analysis of Organisational Benefits & Risks*. Center for Business Services Science. University of Wollongong.

Galle, P. et Kroes, P. (2014). Science and Design: Identical Twins. *Design Studies,* 35(3), 201-231.

Gallear, D.A., Ghobadian, A., Li, Y., O'Regan, N., Childerhouse, P. et Naim, M. (2013). An Environmental Uncertainty-Based Diagnostic Reference Tool for Evaluating the Performance of Supply Chain Value Streams. *Production Planning & Control*, 25(13), 1182-1197.

Gamma, E., Helm, R., Johnson, R. et Vlissides, J. (1995). *Design Patterns: Elements of Reusable Software Architecture*, Reading, MA: Addison-Wesley; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Gann, D.M. (1994). Innovation in the Construction Sector; in Khalfan, M.M.A. *et* McDermott, P. (2006). Innovating for Supply Chain Integration within Construction. *Construction Innovation*, 6(3), 143-157.

George, A. L. et Bennett, A. 2005. *Case Studies and Theory Development in the Social Sciences*, Cambridge, MA: MIT Press; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

George, S. et Tryggestad, K. (2009). On the Emergence of Roles in Construction: The Qualculative Role of Project Management. *Construction Management and Economics*, 27(10), 969-981.

Giddens, A. (1979). *Central Problems in Social Theory: Action, Structure and Contradictions in Social Analysis*, Berkeley, CA University of California Press; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Giddens, A. (1984). *The Constitution of Society: Introduction of the Theory of Structuration*, Berkeley, CA: University of California Press; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Giddens, A. (1993). *New Rules of Sociological Method: A Positive Critique of Interpretative Sociologies.* Stanford, CA: Stanford University Press.

Gill, T. et Hevner, A.R. (2013). A Fitness-Utility Model for Design Science Research. *ACM Transaction on Management Information System*, 4(2), 5.1 – 5.24.

Giovinazzo, W. (2009). Only as Good as Its Data Quality. *Information Management Special Report*; in Isik, O., Jones, M.C, et Sidorova, A. (2011). Business Intelligence (BI) Success and the Role of BI Capabilities. *Intelligent Systems in Accounting, Finance and Management*, 18(4), 161-176.

Glanville, R. (1999). Researching Design and Designing Research. *Design Issues* (15:2), 80-91, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production*. MIS Quarterly*, 39(3), 541-564.

Glaser, J.M. (1996). The Challenge of Campaign watching: Seven Lessons of Participant Observation Research. Political Science and Politics, 29(3), 533-537; in Palsson, H. (2007). Participant Observation in Logistics Research. Experiences from an RFID Implementation Study. *International Journal of Physical Distribution & Logistics Management*. 37(2), 148-163.

Goes, P. B. (2014). Editor's Comments: Design Science Research in Top Information Systems Journals. *MIS Quarterly,* 38(1), iii-viii.

Gold, Raymond L. (1958). Roles in Sociological Field Observations. *Social Forces, 36*, 217-223.

Goldkuhl, G. (2004). Design Theories in Information Systems: A Need for Multi-Grounding. *Journal of Information Technology Theory and Application,* 6(2), 59-72.

Goldkuhl, G. (2012). From Action Research to Practice Research. *Australasian Journal of Information Systems,* 17(2), 57-78.

Gonzalez, M.L. (2011). Success Factors for Business Intelligence and Data Warehousing Maturity and Competitive Advantage. *Business Intelligence Journal*, 16(1), 22-29.

Goodhue, D. L. et Thompson, R. L. (1995). Task-Technology Fit and Individual Performance. *MIS Quarterly*, 19(2), 213-236.

Grandori, A. (1984). A Perspective Contingency View of Organizational Decision Making. *Administrative Science Quarterly*, 29(2), 192-210; in Gallear, D.A., Ghobadian, A., Li, Y., O'Regan, N., Childerhouse, P. et Naim, M. (2013). An Environmental Uncertainty-Based Diagnostic Reference Tool for Evaluating the Performance of Supply Chain Value Streams. *Production Planning & Control*, 25 (13-14), 1182-1197.

Grant, R.M. (1991). The Resource-Based Theory of Competitive Advantage: Implications for Strategy Formulation. *California Management Review*, 33(3), 114-135; in Craighead, C.W. et Shaw, N.G. (2003). E-Commerce Value Creation and Destruction: A Resource Based Supply Chain Perspective. *The Data Base for Advances in Information Systems*, 34(2), 39-49.

Green, S.D., Harty, C. Elmualim, A.A. Larsen, G.D. et Kao, C.C. (2008). On the Discourse of Construction Competitiveness. *Building Research & Information*, 36(5), 426-435; in Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Gregor, S. (2006). The Nature of Theory in Information Systems. *MIS Quarterly*, 30(3), 611-642.

Gregor, S., et Hevner, A. R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. *MIS Quarterly,* 37(2), 337-355.

Gregor, S. et Jones, D. (2007). The Anatomy of a Design Theory. *Journal of the Association for Information Systems,* 8(5), 312-335.

Guba, E. G. (1981a). Criteria for Assessing the Trustworthiness of Naturalistic Inquiries. *Educational Communication and Technology,* 29(2), 75-91; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Gulledge, T. et Chavusholu, T. (2008). *Industrial Management & Data Systems*, 108(6), 750-774.

Gummesson, E. (1988). Qualitative Methods in Management Research, in Venable, J.; Pries-Heje, J. et Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information System*, 25, 77-89.

Gunasekaran, A., Patel, C. et McGaughey, R.E. (2004). A Framework for Supply Chain Performance Measurement. *International Journal of Production Economics*, 87(3), 333-347.

Hammersley, M. (1992). What's Wrong with Ethnography? *Methodological Explorations*, Routledge, London; in Oliver, J. et Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Han, S.H., Chae, M.J., Im, K.S. et Ryu H.D. (2008). Six Sigma-Based Approach to Improve Performance in Construction Operations. *Journal of Management in Engineering*, 24(1), 21-31.

Hannigan, T.J et Palendrano, C. (2002). Personalization Can Be Quite Dynamic. *Information Management Magazine*; in Isik, O., Jones, M.C. et Sidorova, A. (2011). Business Intelligence (BI) Success and the Role of BI Capabilities. *Intelligent Systems in Accounting, Finance and Management,* 18(4), 161-176.

Hammersley, M. e*t* Atkinson P. (1995). Ethnography: Principles and Practice, Routledge, London; in Oliver, J. et Eales, K. (2008). Special Ethics: Re-Evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Harding, W. (2003). Bi-Crucial to Making the Right Decision. *Financial Executive*, 19(2), p. 49-50; in Isik, O., Jones, M.C. et Sidorova, A. (2012). Business Intelligence (BI) Success and the Role of BI Capabilities. *Intelligent Systems in Accounting, Finance and Management*, 18, 161-176.

Hart, P. (2000). Requisite Variety: The Problem with Generic Guidelines for Diverse Genres of Inquiry. *Environmental Education Research, 6* (1), 37-46; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Hein, A.M., Metsker, Y. et Sturm, J. (2014). *Toward a Capability Framework for Systems Architecting and Technology Strategy*. 16th International Dependency and Structure Modelling Conference.

Herder, P. M., Veeneman, W., Buitenhuis, M. et Schaller, A. 2003. Follow the Rainbow: A Knowledge Management Framework for New Product Introduction. *Journal of Knowledge Management,* 7(3), 105-115.

Hevner, A.R (2007). A Three Cycle View of Design Science Research. *A Scandinavian Journal of Information System,* 19(2), 87-92.

Hevner, A.R., March, S.T., Park, J. et Ram, S. (2004). Design Science in Information System Research. *MIS Quarterly*, 28(1), 75-105.

Hook, J., McCarthy, J., Wright, P. et Olivier, p. 2013. Waves: Exploring Idiographic Design for Live Performance, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, New York: ACM, 2969-2978; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Hovorka, D. S. (2010). Incommensurability and Multi-Paradigm Grounding, *Design Science Research: Implications for Creating Knowledge*; in Baskerville, R.L., Kaul, M., et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Howell, Joseph T. (1972). *Hard Living on Clay Street: Portraits of Blue-Collar Families*. Capture 1 December 2018, from https://en.wikipedia.org/wiki/ Participant _observation.

Huan, S. H., Sheoran, S.K. et Wang, G. (2004). A Review and Analysis of Supply Chain Operations Reference (SCOR) Model. *Supply Chain Management: An International Journal*, 9(1), 23-29.

Hult, M. et Lennung, S. (1980). Towards a Definition of Action Research: A Note and Bibliography. *Journal of Management Studies*, 17(2), 241-250.

Hunt, S.D. (2013). A General Theory of Business Marketing: R-A Theory. *Industrial Marketing Management,* 41, 283-293.

Iacovou, C.L., Benbasat, I. et Dexter, A.S. (1995). Electronic Data Interchange and Small Organizations: Adoption and Impact Technology. *MIS Quarterly*, 19(4), 465-485; in Lee, C.-P. et Shim, J.P. (2007). An exploratory Study of Radio Frequency Identification (RFID) Adoption in the Healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Ibn-Homaid, N.T. (2002). A Comparative Evaluation of Construction and Manufacturing Materials Management. *International Journal of Project Management*, 20(4), 263-270.

Ilieva, J., Baron, S. et Healey, N.M. (2002). Online Survey in Marketing Research: Pro and Cons. *International Journal of Market Research*, 44(3), 361-382.

Iivari, J. (2007). A Paradigmatic Analysis of Information Systems as a Design Science," *Scandinavian Journal of Information Systems,* 19(2), 39-64; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Isik, O., Jones, M.C. et Sidorova, A. (2011). Business Intelligence (BI) Success and the Role of BI Capabilities. *Intelligent Systems in Accounting, Finance and Management,* 18(4), 161-176.

Itami, H. (1987). Mobilizing Invisible Assets. Harvard University Press. Cambridge, MA 1987; in Matta, F.J., Fuerst, W.L. et Barney, J.B. (1988). Information Technology and Sustained Competitive Advantage: A Resource-Based Analysis. *MIS Quarterly*, 19(4), 487-494.

Jackson, B.J. (2004). Construction Management Jump Start. Wily Publishing. Indianapolis, IN., 329.

Jackson, P. (1983). Principles and Problems of Participant Observation. Geografiska Annaler, *Human Geography*, 65(1), 39-46; in Palsson, H. (2007). Participant Observation in Logistics Research. Experiences from an RFID Implementation Study. *International Journal of Physical Distribution & Logistics Management*. 37(2), 148-163.

Jang, W.-S. et Skibniewski, M.J. (2009). Cost-Benefit Analysis of Embedded Sensor System for Construction Materials Tracking. *Journal of Construction Engineering and Management*, 135(5), 378-386.

Järvinen, P. (2007). Action Research Is Similar to Design Science. *Quality and Quantity,* 41(1), 37-54; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Jaselskis, E.J. (2003). Implementing Radio Frequency Identification in the Construction Process. *Journal of Construction Engineering and Management*, 129(6), 680-688.

Johansson, M. et Persson, F. (2011). Towards a SCOR-based Analysis Tool for Construction Management and Logistics; in Thunberg, M. et Persson, F. (2013). Using the SCOR Model's Performance Measurements to Improve Construction Logistics. *Production Planning & Control*, 25(13), 1065-1078.

Jones, J. C. (2009). What Is Designing? in *Design Studies: A Reader,* H. Clark and D. Brody (eds.), New York: Berg Publishers, 77-80; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Jones, P., Clarke-Hi, C., Shears, P., Comfort, D. et Hillier, D. (2004). Radio Frequency Identification in the UK: Opportunities and Challenges. *International Journal of Retail & Distribution*, 32(3), 164-71.

Jorgensen, D.I. (1989). Participant Observation: Methodology for Human Studies, Sage, Newbury Park, CA; in Oliver, J. et Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Kain, J.F. (1990). Deception in Dallas: Strategic Misrepresentation in Rail Transit Promotion and Evaluation. *Journal of the American Planning Association*, 56 (2), 184–96.

Kane, G.C., Palmer, D., Phillips, A.N., Kiron, D. et Buckley, N. (2016). Aligning the Organization for its Digital Future. *MIT Sloan Management Review*, 58(1), 3-18.

Kaplan, R.S. (1998). Innovation Action Research: Creating New Management Theory and Practice. *Journal of Management Accounting Research*, 10, 89-118.

Karim, K., Marosszeky, M. et Davis, S. (2006). Managing Subcontractor Supply Chain for Quality in Construction. *Engineering, Construction and Architectural Management*, 13(1), 27-42.

Keller, R.T. (1994). Technology-Information Processing Fit and the Performance of R&D Project Groups: A Test of Contingency Theory. *Academy of Management Journal*, 37(1), 167-178.

Kemmis, S., McTaggart, R. et Retallic, J. (2004), The Action Research Planner, 2nd Ed., Springer, Australia; in Oliver, J. *et* Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Kerlinger, F. N. (1973). *Foundations of Behavioral Research*, New York: Holt, Rinehart and Winston; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Khalfan, M.M.A. et McDermott, P. (2006). Innovating for Supply Chain Integration within Construction. *Construction Innovation*, 6(3), 143-157.

Khazanchi, D. (2005). Information Technology (IT) Appropriateness: The Contingency Theory of Fit and IT Implementation in Small and Medium Enterprises. *The Journal of Computer Systems*, 45(3), 88-95.

Kim, W.C et Mauborgne, R. (2005). *Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant*. Harvard Business School Press, Boston, MA.

Kini, D. (1999). Material Management. The Key to Successful Project Management. *Journal of Management Engineering,* 30-34; in Young, D.A.; Hass, C.T., Goodrum, P. et Caldas, C. (2011). Improving Construction Supply Networking Visibility by Using Automated Materials Locating and Tracking Technology. *Journal of Construction Engineering and Management*, 137(11), 976-984.

Klecun, E. et Cornford, T. (2005). A Critical Approach to Evaluation. *European Journal of Information System*, 14(3), 229-243.

Klein, H. K., et Myers, M. D. (1999). A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems. *MIS Quarterly,* 23(1), p. 67-93, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Knight, F. (1965). Risk, Uncertainty and Profit, Harper and Row, New York, NY; in Benton, W.C., et McHenry, L. (2010). *Construction Purchasing & Supply Chain Management*. McGraw Hill, NY.

Kogut, B. et Zander, U. (1997). Knowledge of the Firm: Combinative Capabilities, and the Replication of Technology; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Koutsoukis, N.S., Dominguez-Ballesteros, B., Lucas, C.A. et Mitra, G. (2000). A Prototype Decision Support System for Strategic Planning under Uncertainty. *International Journal of Physical Distribution and Logistics Management*, 30 (7), 640-660; in Gallear, D.A., Ghobadian, A., Li, Y., O'Regan, N., Childerhouse, P. et Naim, M. (2013). An Environmental Uncertainty-Based Diagnostic Reference Tool for Evaluating the Performance of Supply Chain Value Streams. *Production Planning & Control*, 25 (13-14), 1182-1197.

Krotov, V. et Junglas, I. (2008). RFID as a disruptive innovation. *Journal of Theoretical and Applied Electronic Commerce Research*, 3(2), 44-59.

Kuechler, W. et Vaishnavi, V. (2012). A Framework of Theory Development in Design Science Research: Multiple Perspective. *Journal of the Association for Information System*, 13(6), 395-423.

Kuechler, W. et Vaishnavi, V. (2008). The Emergence of Design Science Research in Information Systems in North America. *Journal of Design Research*; in Kuechler, B. et Vaishnavi, V. (2008). Theory Development in Design Science Research: Anatomy of a Research Project. *Proceeding of the 3rd International Conference on Design Science Research in Information System and Technology*, May7-9, Atlanta, GA.

Kuechler, W., Vaishnavi, V. et Pertter, S. (2005). The Aggregate General Design Cycle as a Perspective on the Evolution of Computing Communities of Interest. *Computing Letters* 1(3), 123-128; in Kuechler, B. et Vaishnavi, V. (2008). Theory Development in Design Science Research: Anatomy of a Research Project. *Proceeding of the 3rd International Conference on Design Science Research in Information System and Technology*, May7-9, Atlanta, GA.

Flyvbjerg, B., Bruzelius, N., et Rothegatter, W. (2003). *Megaprojects and Risk, An Anatomy of Ambition*. Cambridge University Press, 201.

Lai, P.C. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*, 14(1), 21-38.

Landry, M. et Banville, C. (1992). A Disciplined Methodological Pluralism for MIS Research," *Accounting, Management and Information Technologies,* 2(2), 77-97.

Lambert, D.M., Garcia-Dastugue, S.J. *et* Croxton, K.L. (2005). An Evaluation of Process-Oriented Supply Chain Management Frameworks. *Journal of Business Logistics*, 26(1), 25-21.

Latham, M. (1994). *Constructing the Team*. London: HMSO; in Thunberg, M. et Persson, F. (2013). Using the SCOR Model's Performance Measurements to Improve Construction Logistics. *Production Planning & Control*, 25(13-14), 1065-1078.

Lazarus, D. et Clifton, R. (2001). Managing Project Change: *A Best Practice Guide, CIRIA*, London; in Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Lee, C.-P. et Shim, J.P. (2007). An exploratory Study of Radio Frequency Identification (RFID) Adoption in the healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Lee, H. (2004). The Triple-A Supply Chain. *Harvard Business Review*, 82(10), 102-112.

Lee, H.L. (2002). Aligning Supply Chain Strategies with Product Uncertainties. *California Management Review*, 44(3), 105-119.

Li, S., Visich, J.K., Khumawala, B.M., et Zhang, C. (2006). Radio Frequency Identification Technology: Application, Technical Challenges and Strategies. *Sensor Review*, 26 (3), 193-202.

Lie, S. Ragu-Nathan, B., Ragu-Nathan, T.S. et Subba Rao, S. (2006). The Supply Chain Management Practices on Competitive Advantages and Organizational Performance. *Omega*, 34, 107-124.

Lieberman, M.B. et Montgomery, D.B. (1988). First-Mover Advantages, *Strategic Management Journal,* (special issues), 41-58; in Matta, F.J., Fuerst, W.L. et Barney, J.B. (1995). Information Technology and Sustained Competitive Advantage: A Resource-Based Analysis. *MIS Quarterly*. 19(4), 487-494.

Lincoln, Y. S., et Guba, E. G. (1985). *Naturalistic Inquiry*, Newbury Park, CA: SAGE Publications; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Ling, F.Y.Y. (2003). Managing the Implementation of Construction Innovations. *Construction Management and Economics*, 21(6), 635-649.

Lippman, S. et Rumelt, R.P. (1982). Uncertainty Imitability: An Analysis of Interfirm Differences in Efficiency Under Competition. *Bell Journal of Economics*, 13, 418-438; in Reed, R. et De Fillippi, R.J. (1990). Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage. *The Academy of Management Review,* 15 (1), 88-102.

Liu, P., Huang, A. Mokasdar, H., Zhou, H. et Hou, L. (2013). The Impact of Additive Manufacturing in the Aircraft Spare Parts Supply Chain: Supply Chain Operations Reference (SCOR) Model Based Analysis. Production Planning & Control; in Chan, H.K. et Kumar, V. (2014). Special Issue – Applications of Reference Models for Supply-Chain Integration. *Production Planning & Control*, 25(14), 1059-1064.

Lockmy III, A. et McCormack, K. (2004). Linking SCOR Planning Practices to Supply Chain Performance: An Exploratory Study. *International Journal of Operations & Production Management*, 24(12), 1192-1218.

Lonnqvit, A. et Pirttimaki, V. (2006). The Measurement of Business Intelligence. *Information Systems Management,* 23(1), 32-40.

Lopez, R., Love, P.E.D., Edwards, D.J. et Davis, P.R. (2010). Design Error Classification, Causation and Prevention in Construction Engineering. *Journal of Performance of Constructed Facilities*, 24(4), 399-408.

Love, P.E. et Li, H. (2000). Quantifying the Causes and Costs of Rework in Construction. *Construction Management and Economics*, 18(4), 479-490.

Ludwig, G. et Pemberton, J. (2011). A Managerial Perspective of Dynamic Capabilities in Emerging Markets: the case of the Russian steel industry. *Journal of East European Management Studies*, 16(3), 215-236.

MacFarlane, D. et Sheffi, Y. (2003). The Impact of Automatic Identification on Supply Chain Operations. *International Journal of Logistics Management*, 14(1), 1-17.

Maqsood, T. et Finegan, A.D. (2009). A Knowledge Management Approach to Innovation and Learning in the Construction Industry. *International Journal of Managing Projects in Business*, 2(2), 297-307.

Mahoney, J.T. et Pandian, J.R. (1992), The Resource-Based View Within the Conversation of Strategic Management. *Strategic Management Journal*; 15(5), 363–380.

Makadok, R. (2001), Toward a Synthesis of the Resource-Based View and Dynamic-Capability Views of Rent Creation. *Strategic Management Journal*; 22(5), 387–401.

March, S. et Smith, G. (1995). Design and Natural Science Research Information Technology. Decision Support Systems, 15, 251-266; in Gregor, S. et Hevner, A.R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly, 37(2), 337-355.

Markus, M. L., Majchrzak, A. et Gasser, L. (2002). A Design Theory for Systems That Support Emergent Knowledge Processes. *MIS Quarterly,* 26(3), 179-212.

Martin, R. L. (2009). *The Design of Business: Why Design Thinking Is the Next Competitive Advantage*, Boston: Harvard Business School Press; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), A4-A9.

Matta, F.J., Fuerst, W.L. et Barney, J.B. (1995). Information Technology and Sustained Competitive Advantage: A Resource-Based Analysis. *MIS Quarterly,* 19(4), 487-494.

Matta, V. et Koonce, 2D. (2009). Semantic Breakdown of RFID Functionality to Support Application Development. *Journal of Computer Systems*, 49(3), 54-59.

McKay, J. et Marshall, P. (2001). The Dual Imperatives of Action Research. *Information Technology & People,* 14(1), 46-59.

McLennan, G. (2001). Critical or Positive Theory? A Comment on the Status of Anthony Giddens' Social Theory; in Bryant, C.G.A. et Jary, D. (1996). *Anthony Giddens: Critical assessments* New York, NY: Routledge,

McNiff, J; Whitehead, J. (2005). *All You Need to Know About Action Research.* Capture 1 May 2018, from https://en.wikipedia.org/wiki/Action_research

Melnyk, S.A., Stewart, D.M. et Swink, M. (2004). Metrics and Performance Measurement in Operations Management: Dealing with the Metrics Maze. *Journal of Operations Management*, 22(3), 209-219; in Gallear, D.A., Ghobadian, A., Li, Y., O'Regan, N., Childerhouse, P. et Naim, M. (2013). An Environmental Uncertainty-Based Diagnostic Reference Tool for Evaluating the Performance of Supply Chain Value Streams. *Production Planning & Control*, 25(13), 1182-1197.

Mentzer, J.T. et Kahn, K.B. (1995). A Framework of Logistics Research. *Journal of Business Logistics*. 16(1), 231-250.

Merton, Robert K. (1968). *Social Theory and Social Structure*. Capture 1 July 2018, from https://en.wikipedia.org/wiki/Structuration_theory

Meyer, M. (2000). Innovation Roles: From Souls of Fire to Devil's advocates. *The Journal of Business Communication*, 37(94), 328-347; in Lee, C.-P. et Shim, J.P. (2007). An exploratory Study of Radio Frequency Identification (RFID) Adoption in the Healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Muehlhausen, F.B. (1991). Construction Site Utilisation: Impact of Material Movement and Storage for Productivity and Cost. *American Association of Cost Engineers*, Paper L.2., 1-9.

Ngai, E.W.T. et Gunasekaran, A. (2009). RFID Adoption: Issues and challenges. *International Journal of Enterprise Information Systems*, 5(1), 1-8.

Ngai, E.W.T., Moon, K.K.L., Riggins, F.J. et Candace, Y.Y. (2008). RFID Research: An Academic Literature Review (1995-2005) and Future Research Directions. *International Journal of Production Economics*, 112(2), 510-520.

Negash, S. (2004). Business Intelligence. *Communications of the Association for Information Systems*, 13, 177-195; in Isik, O., Jones, M.C, et Sidorova, A. (2011). Business Intelligence (BI) Success and the Role of BI Capabilities. *Intelligent Systems in Accounting, Finance and Management*, 18(4) 161-176.

Niederman, F. et March, S. T. (2012). Design Science and the Accumulation of Knowledge in the Information Systems Discipline. *ACM Transactions on Management Information Systems,* 3(1), 1-10.

Niehaves, B. (2007). On Epistemological Pluralism in Design Science. *Scandinavian Journal of Information Systems,* (19:2), 93-104, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Oliver, J. et Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Osteraker, M.C. (1999). Measuring Motivation in a Dynamic Organisation: A Contingency Approach. *Strategic Change*, 8(2), 103-109.

Österle, H., Becker, J., Frank, U., Karagiannis, D., Krcmar, H., Loos, P., Mertens, P., Oberweis, A. et Sinz, E.J. (2011). Memorandum on Design-Oriented Information Systems Research. *European Journal of Information System*, 20(1) 7-10.

Palsson, H. (2007). Participant Observation in Logistics Research. Experiences from an RFID Implementation Study. *International Journal of Physical Distribution & Logistics Management*. 37(2), 148-163.

Parasuraman, A., & Colby L. C. (2001). *Techno-Ready Marketing*. The Free Press; in Lai, P.C. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*, 14(1), 21-38.

Parmenter D. (2010). Key Performance Indicators. Developing Implementing and Using Winning KPIs. *John Wiley & Sons*, 2nd Ed, NJ.

Paul L., John I. et Pierre, C. (2003). Why Do People Use Information Technology? A Critical Review of the Technology Acceptance Model. *Information & Management*, 40(3), 191–204.

Pavlou, P.A. et Majchrzak, A. (2002). Structuration Theory: Capturing the Complexity of Business-to-Business Intermediaries; in M. Warkentin (2001), *Business to Business Electronic Commerce: Challenges & Solutions.* Hershey, PA: Idea Group Publishing. Capture 1 May 2018.

Peffers K., Tuunanen, T., Rothenberger, M.A. et Chaterjee, S. (2008). A Design Science Research Methodology for Information System Research. *Journal of Management Information Systems*, 24(3), 45-77.

Petroski, H. (2009). *What Is Designing*? in *Design Studies: A Reader,* H. Clark and D. Brody (eds.), New York: Berg Publishers, 89-95; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

PicardConsult, LCC. (2009). *Introduction to Continuous Improvement of the Construction & Maintenance Work Process*. Conference AACE Toronto, 2009.

Plemmons, J.K. (1995). *Material Management Process Effectiveness Measures and Benchmarking in the Industrial Construction Industry*. Ph.D. Thesis, Clemson University, Clemson, S.C.; in Torrent, D.G. et Caldas, C. (2009). Methodology for Automating the Identification and Localization of Construction Components on Industrial Projects. *Journal of Computing in Civil Engineering*, 23, 3-13.

PMBOK Guide and Standard, Capture 1 May 2018, from https://pmi.org/pmbok-guide-standards

Porter, M.E. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance:* NY Free Press; in Reed, R. et De Fillippi, R.J. (1990). Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage. *The Academy of Management Review*, 15 (1), 88-102.

Powell, G. (2012). Construction Contract Preparation and Management: From Concept to Completion, Palgrave Macmillan, Basingstoke; in Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Prahalad, C.K. et Hamel, G. (1990). The Core Competence of the Corporation. *Harvard Business Review*, May-June 1990, 79-91.

Priem, R.L. et Butler, J.E. (2001a), Is the Resource-Based Theory a Useful Perspective for Strategic Management Research? *Academy of Management Review*; 26, (1), 22–40.

Priem, R.L. et Butler, J.E. (2001b), Tautology in the Resource-Based View and Implications of Externally Determined Resource Value: Further Comments. *Academy of Management Review*; 26, (1), 57–66.

Pries-Heje, J., Venable, J. et Baskerville, R. (2014). Soft Design Science Methodology, in *Situated Design Methods,* Cambridge, MA: MIT Press, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Rai, A. et Patnayakuni, R. (1996). A Structural Model for Case Adoption Behavior. *Journal of Management Information Systems*, 13(2), 205-234.

Ranasinghe, D.C., Engles, D.W., et Cole, P.H. (2004). Low Cost RFID Systems: Confronting Security and Privacy; in Li, S., Visich, J.K., Khumawala, B.M. et Zhang, C. (2006). Radio Frequency Identification Technology: Application, Technical Challenges and Strategies. *Sensor Review*, 26 (3), 193-202.

Rapoport, R.N. (1970). Three Dilemmas in Action Research: With Special Reference to the Tavistock Experience. *Human Relations*, 23(6), 499-513.

Ray, G.B., Barney, J.B. et Muhanna, W.A. (2004). Capabilities, Business Process Competitive Advantage: Choosing the Dependent Variable in Empirical Tests of the Resource-Based View. *Strategic Management Journal*, 25(1), 23-37; in Sangari, M.S. *et* Razmi, J. (2015). Business Intelligence, Competence, Agile Capabilities, and Agile Performance in Supply Chain. *The International Journal of Logistics Management*, 26(2), 356-380.

Reason, P. & Bradbury, H. (2013). The SAGE Handbook of Action Research. Participative Inquiry and Practice (2nd ed). Capture 1 May 2018, from https://en.wikipedia.org /wiki/Action _research

Reed, R. et DeFillippi, R.J. (1990). Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage. *The Academy of Management Review*, 15 (1), 88-102.

Reyes, P.M. et Frazier, G.V. (2007). Radio Frequency Identification: Past, Present and Future Business Applications. *International Journal of Integrated Supply Management*, 3(2), 125-134.

RFID Journal, Sept 22, 2003. Feature: Seven Reasons to Act Now in, Angeles, R. (2005). RFID Technologies: Supply Chain Applications and Implementation Issues. *Information Systems Management*, 22(1), 51-65.

Robey, D. (1996). Research Commentary: Diversity in Information Systems Research: Threat, Promise, and Responsibility. *Information Systems Research*, 7(4), 400-408.

Robillard, P. N. 1999. The Role of Knowledge in Software Development. *Communications of the ACM,* 42 (1), 87-92.

Robson, C. (2002). *Real World Research. A Resource for Social Scientists and Practitioner & Researchers*. 2nd ed., Blackwell Publishing. Oxford, U.K.

Rogers, E.M. (1995). Diffusion of Innovations. 4th ed., New York: The Free Press; in Lai, P.C. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*, 14(1), 21-38.

Romme, A. G. L. (2003). Making a Difference: Organization as Design. *Organization science* 14(5), 558-573; in Baskerville, R.L., Kaul, M., et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Ross, A.D., Twede, D., Clarke, R.H., et Ryan, M. (2009). A Framework for Developing Implementation Strategies for Radio Frequency Identification (RFID) System in a Distribution Center Environment. *Journal of Business Logistics*, 30(1), 157-182.

Rotimi, F.E., Tookey, J., Craig, N. et Rotimi, J.O.B. (2011). *Opportunities for Defect Reporting in New Residential Buildings: A Case Study for New Zealand*; in Taggart, M., Koskela, L. et Rooke, J. (2014). The Role of the Supply Chain in the Elimination and Reduction of Construction Rework and Defects: An Action Research Approach. *Construction Management and Economics*, 32(7-8), 829-842.

Rungtusanatham,M., Salvador, F., Forza, C. et Choi, T.Y. (2003). Supply Chain Linkage and Operational Performance: A Resource-Based-View Perspective. *International Journal of Operations & Production Management*, 23(9), 1084-1099; in Cannon, A.R. et Reyes, P.M. (2008). RFID in the Contemporary Supply Chain: Multiple Perspectives on its Benefits and Risks. *International Journal of Operations & Production Management*, 28(5), 433-454.

Sabbaghi, A. et Vaidyanathan, G. (2008). Effectiveness and Efficiency of RFID Technology in Supply Chain Management: Strategic Values and Challenges. *Journal of Theoretical and Applied Electronic Commerce Research*, 3(2), 71-82.

Sabri, E.H. et Beamon, B.M. (2000). A Multi-Objective Approach to Simultaneous Strategic and Operational Planning in Supply Chain Design. *Omega*, 28(5), 581-598, in Gallear, D.A., Ghobadian, A., Li, Y., O'Regan, N., Childerhouse, P. et Naim, M. (2013). An Environmental Uncertainty-Based Diagnostic Reference Tool for Evaluating the Performance of Supply Chain Value Streams. *Production Planning & Control*, 25 (13-14), 1182-1197.

Sachan, A. et Datta, S. (2005). Review of Supply Chain Management and Logistics Research. *International Journal of Physical Distribution & Logistics Management*. 35(9), 664-705.

Sadler, P. (1996). Managing Change, Kogan Page, London, in Lee, C.-P. et Shim, J.P. (2007). An Exploratory Study of Radio Frequency Identification (RFID) Adoption in the Healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Sanghera, P. (2006). *PMP in Depth: Project Management Professional Study Guide for PMP and CAPM Exams*. 3rd Ed. Thompson Course Technology, New York, NY, 8-9.

Sangari, M.S. et Razmi, J. (2015). Business Intelligence, Competence, Agile Capabilities, and Agile Performance in Supply Chain. *The International Journal of Logistics Management*, 26(2), 356-380.

Sardroud, J.M.; Limbachiya, M.C. et Saremi, A. A. (2009). Ubiquitous Tracking and Locating of Construction Resource Using GIS and RFID. Capture 3 May 2015 from htpp://www.SID.ir.

Savransky, S. (2000). Engineering of Creativity, Boca Raton, FL, CRC Press; in Gregor, S. et Hevner, A.R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly, 37(2), 337-355.

Schwartz, M.S.; Schwartz Green, C. (1955). *Problems in Participant Observation.* Capture 1 December 2018, from https://en.wikipedia.org/wiki/Participant _observation

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., et Lindgren, R. (2011). Action Design Research. *MIS Quarterly,* 35(2), 37-56.

Sellitto, M.A., Pereira, G.M., Borchardt, M., de Silva, R.I., et Viegas, CV. (2015). A SCOR-based Model for Supply Chain Performance Measurement: Application in the Footwear Industry. *International Journal of Production Research*, 53(16), 4917-4926.

Senaratne, S. et Sexton, M. (2008). Managing Construction Project Change: A Knowledge Management Perspective. *Construction Management and Economics*, 26(12), 1303-1311.

Seuring, S. (2006). The Rigor of Case Study in Supply Chain Management; in Palsson, H. (2007). Participant Observation in Logistics Research. Experiences from an RFID Implementation Study. *International Journal of Physical Distribution & Logistics Management*. 37(2), 148-163.

Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Silver, E. (1988). Materials Management in Large-Scale Construction Project: Some Concerns and Research Issues. *Engineering Costs and Production Economics*, 15, 223-229.

Simichi-Levi, D., Simichi-Levi, E. et Kaminsky, P. (2008). *Designing and Managing the Supply Chain: Concepts, Strategies and Cases*. 3rd ed., McGraw-Hill, New York, NY; in Chan, H.K. et Kumar, V. (2014). Special Issue – Applications of Reference Models for Supply-Chain Integration. *Production Planning & Control*, 25(13-14), 1059-1064.

Simon, H. A. (1988). The Science of Design: Creating the Artificial, *Design Issues,* 4 (1/2), 67-82; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production*. MIS Quarterly*, 39(3), 541-564.

Simon, H. A. (1996). *The Sciences of the Artificial. 3rd* ed., Cambridge, MA: MIT Press; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production*. MIS Quarterly*, 39(3), 541-564.

Smart, A.Y, Bunduchi, R. et Gerst, M. (2010). The Costs of Adoption of RFID Technologies in Supply networks. *International Journal of Operations & Production Management*, 30(4), 423-447.

Smith, A.D. (2005). Exploring Radio Frequency Identification Technology and its Impact on Business Systems. *Information Management and Computer Security*, 13(1), 16-28.

Smith-Daniels, D. et Aquilano, N.J. (1984). Constraint Resource Project Scheduling Subject to Material Constraints. *Journal of Operations Management*, 4, 369-387.

Sobotka, A., Czarnigowsky, A., et Stefaniak, K. (2005). Logistics of Construction Projects. *Foundations of Civil and Environmental Engineering*, 6, 203-216.

Sosnoski, J.J. (1993). A Mindless Man-Driven Theory Machine: Intellectuality, Sexuality, and the Institution of Criticism. *Feminisms: An Anthology of Literary Theory and Criticism*, New Brunswick, N.J.: Rutgers University Press.

Spekman, R.E. et Sweeney, P.J. (2006). RFID: From Concept to Implementation. *International Journal of Physical Distribution & Logistics Management*, 36(10), 736-754.

Spradley, James P. (1980). *Participant Observation*. Capture 1 December 2018, from https://en.wikipedia.org/wiki/Participant observation.

Srivastava, B. (2004). Radio frequency ID Technology: The next revolution in SCM. *Business Horizons*, 47(6), 60-68.

Stefanou, C.J. (2001). A Framework for the Ex-Ante Evaluation of ERP Software. *European Journal of Information System*, 10(4), 204-215.

Sternberg, R., Kaufman, J., *et* Pretz, J. (2002). The Creativity Conundrum: A Propulsion Model of Kinds of Creative Contribution. Psychology Press, New York, NY; in Gregor, S. et Hevner, A.R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly, 37(2), 337-355.

Stokes, D. (1997). Pasteur's Quadrant: Basic Science and Technological Innovation. Brooklyn Institute Press, Washington, DC; in Gregor, S. et Hevner, A.R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly, 37(2), 337-355.

Stock, J.R *et* Lambert, D.M. (2000). Strategic Logistics Management. 4th Ed. McGraw-Hill Irvin, Toronto, ON.

Stones, R. (2005). *Structuration Theory.* Palgrave Macmillan, New York, NY:

Strandholm, K., Kumar, K. et Subramanian, R. (2004). Examining the Interrelationships Among Perceived Environmental Change, Strategic Response, Managerial Characteristics, and Organizational Performance. *Journal of Business Research*, 57(1), 58-59.

Strauss, A. et Corbin, J. (1998). Basics of Qualitative Research, Sage, Thousand Oaks, CA; in Palsson, H. (2007). Participant Observation in Logistics Research. Experiences from an RFID Implementation Study. *International Journal of Physical Distribution & Logistics Management*. 37(2), 148-163.

Sun, Y. *et* Kantor, P.B. (2006). Cross-Evaluation: A New Model for Information System Evaluation. *Journal of American Society for Information Science and Technology*, 57(5), 614-628; in Venable, J.; Pries-Heje, J. et Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information System*, 25(1), 77-89.

Susman, G.I. et Evered, R.D. (1978). An Assessment of the Scientific Merits of Action Research. *Administrative Science Quarterly*, 23(4), 582-603.

Taggart, M., Koskela, L. et Rooke, J. (2012). Collaborative Supply Chain Practice During Severe Economic Downturn in the Republic of Ireland; in Taggart, M., Koskela, L. et Rooke, J. (2014). The Role of the Supply Chain in the Elimination and Reduction of Construction Rework and Defects: An Action Research Approach. *Construction Management and Economics*, 32(7-8), 829-842.

Taggart, M., Koskela, L. et Rooke, J. (2014). The Role of the Supply Chain in the Elimination and Reduction of Construction Rework and Defects: An Action Research Approach. *Construction Management and Economics*, 32(7-8), 829-842.

Tah J.H (2005). Toward an Agent-Based Construction Supply Chain Network Modeling and Simulation Platform. *Automation Construction*, 15(2), 66-177.

Taylor, S. et Todd, P. A. (1995). Understanding Information Technology Usage: A Test of Competing Models. *Information Systems Research*, 6(2), 144-176.

Tedlock, B. (2000). Ethnography and Ethnographic Representation, in Oliver, J. et Eales, K. (2008). Special Ethics: Re-evaluating the Consequentialist Perspective of Using Covert Participant Observation in Management. *Qualitative Market Research: An International Journal*, 11(3), 344-357.

Teece, D., Pisano, G. et Shuen, A. (1997). Dynamic Capability and Strategic Management. *Strategic Management Journal*, 18(7), 509-533.

Teicholz, P. (2013). Labor-Productivity Declines in the Construction Industry: Causes and Remedies. *AECBytes,* 67(3), 1-11.

Teichroeb, R. (1990). *Canadian Blessing for Chinese Dam Called Prostitution*. Winnipeg Free Press, 20 September, 9.

Teo, T.S.H., et Ranganathan, C. (2004). Adopters and Non-Adopters of Business-to-Business Electronic Commerce in Singapore. Information & Management, 42(1), 89-102.

Thiel, D. (2013). Ethnography and Flux: Identity and Epistemology in Construction Fieldwork. Ethnographic Research in the Construction Industry, Routledge, Abingdon, 73-90; in Shipton, C., Hughes, W., *et* Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Thomas, H.R., Riley, D.R. et Messner, J.I. (2005). Fundamental principles of site material management. *Journal Construction Engineering Management*, 131(7), 808-815.

Thompson, L.F., Surface, E.A., Martin, D.L. et Sanders, M.G. (2003). From Paper to Pixel: Moving Personnel Surveys to the Web. Personnel Psychology, 56(1), 197-227; in Lee, C.-P. *et* Shim, J.P. (2007). An Exploratory Study of Radio Frequency Identification (RFID) Adoption in the Healthcare Industry. *European Journal of Information Systems*, 16(6), 712-724.

Thunberg, M. et Persson, F. (2013). Using the SCOR Model's Performance Measurements to Improve Construction Logistics. *Production Planning & Control*, 25(13-14), 1065-1078.

Torrent, D.G. et Caldas, C. (2009). Methodology for Automating the Identification and Localization of Construction Components on Industrial Projects*. Journal of Computing in Civil Engineering*, 23(1), 3-13.

Tsoukas, H. (1989). The Validity of Idiographic Research Explanations. *Academy of Management Review,* 14 (4), 551-561.

Tutt, D.E., Pink, S., Dainty, A. et Gibb, A. (2013). We've Got Our Own Language: The Communication Practices of the Migrant Workers in the UK Construction Industry; in Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Vaishnavi, V. *et* Kuechler, W. (2004). Design Research in Information Systems. January 20, 2004; in Kuechler, B. et Vaishnavi, V. (2008). Theory Development in Design Science Research: Anatomy of a Research Project. *Proceeding of the 3rd International Conference on Design Science Research in Information System and Technology*, May7-9, Atlanta, GA.

Vaishnavi, V. *et* Kuechler, W. (2004). Design Science Research in Information Systems; in Venable, J.; Pries-Heje, J. et Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information System*, 25(1), 77-89.

Vaishnavi, V. K., and Kuechler, W. 2007. *Design Science Research Methods and Patterns: Innovating Information and Communication Technology*, Boca Raton, FL: Auerbach Publications; in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Van Aken, J. E. 2004. Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules. *The Journal of Management Studies* (41:2), 219-246.

Van de Ven, A.H. et Drazin, R. (1985). The Concept of Fit in Contingency Theory. The Strategic Management Research Center. University of Minnesota. Minneapolis, MN.

Van der Vorst, J.G.A.J. et Beulens, A.J.M. (2002). Identifying Sources of uncertainties to Generate Supply Chain Redesign Strategies. *International Journal of Physical Distribution & Logistics Management*, 32(6), 409-430.

Van Maanen, J. (1998). *Tales of the FIELD: On Writing Ethnography.* University of Chicago Press, London; in Shipton, C., Hughes, W. et Tutt, D. (2014). Change Management in Practice: An Ethnographic Study of Changes to Contract Requirement on Hospital Project. *Construction Management and Economics*, 32(7-8), 787-803.

Van Rensburg, A. (2006). The Value Chain as an Operations Reference Model. Capture 4 July 2015 from htpp://www.value-chain.org

Venable, R. (2006). A Framework for Design Science Research Activities, in Emerging Trends and Challenges in Information Technology Management, in Venable, J.; Pries-Heje, J. et Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information System*, 25, 77-89.

Venable, J. (2006). *The Role of Theory and Theorizing in Design Science Research*. Proceedings DESRIST 2006, Claremont, CA; in Kuechler, B. et Vaishnavi, V. (2008). *Theory Development in Design Science Research: Anatomy of a Research Project*. Proceeding of the 3rd International Conference on Design Science Research in Information System and Technology, May 7-9, Atlanta, GA

Venable, J.; Pries-Heje, J., et Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information System*, 25(1), 77-89.

Venkatraman, N. (1994). IT-Enabled Business Transformation: From Automation to Business Redefinition. Sloan Management Review, 35(2), 73-87.

Venkatesh, V. et Davis, F. D. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science*, 46 (2), 186-204.

Venkatesh, V., Morris, M.G., Davis, F.D. et Davis, G.B. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*, 27, 425-478.

Venkatesh, V. et Bala, H. (2008). Technology Acceptance Model 3 and a Research Agenda on Interventions. *Decision Science*, 39 (2), 273-312.

Verkerke, G.J., van der Howen, E.B., Broekhuis, A.A., Bursa, J., Catapano, G., McCullagh, P., Mottaghy, K., Niederer, P., Reilly, R., Rogalewicz, V., Segers, P. et Verdonschot, N. (2013). Science versus Design: Comparable, Constrastive or Conducive. *Journal of the Mechanical Behavior of Biomedical Materials*, 21(0), 195-201.

Vinten, G. (1994). Participant Observation: A Model for Organizational Investigation? *Journal of Managerial Psychology*, 9(2), 30-39.

Von Hippel, E. (1986). Lead Users: A Source of Novel Product Concepts. *Management Science,* 32 (7), 791-805, in Baskerville, R.L., Kaul, M. et Storey, V.C. (2015). Genres of Inquiry in Design-Science Research: Justification and Evaluation of Knowledge Production. *MIS Quarterly*, 39(3), 541-564.

Vrijhoef, R. et Koskela, L. (2000). The Four Roles of Supply Chain Management in Construction. *European Journal of Purchasing and Supply Chain Management*, 6(3-4), 169-178.

Wachs, M. (1989). When Planners Lie with Numbers. *Journal of the American Planning Association*, 55(4), 476–479.

Walls, J., Widmeyer, G. et El Sawy, O. (2004). Assessing Information System Design Theory in Perspective: How Useful was our 1992 Initial Rendition. *Journal of Information Technology Theory and Application*, 6(2), 43-58.

Walls, J.G., Widmeyer, G.R. et El Sawy, O.A. (1992). Building an Information System Design Theory for Vigilant EIS. *Information System Research*, 3(1), 36-59.

Wang, Q. et Dai, J. (2014). Construction of Intelligent Logistics Platform Based on the Internet of Things Management Model. 2014 *International Conference of Logistics Engineering and Management*, Shanghai, China.

Wernerfelt, B. (1984). A Resource-Based View of the Firm. *Strategic Management Journal*, 5, 171-180.

Whitworth, A. et Cheatham, C. (1988). Appraisal Manipulation: Appraisal of the Yonki Dam Hydroelectric Project. *Project Appraisal*, 3(1), 13–20.

William, D. *et* Black, P. (1996). Meaning and Consequences: A Basis for Distinguishing Formative and Summative Functions of Assessment? *British Educational Research Journal*, 22(5), 537-548.

Wilson, J. (2002). Responsible Authorship and Peer Review. Science and Engineering Ethics, 8(2), 155-174; in Gregor, S. et Hevner, A.R. (2013). Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly, 37(2), 337-355.

Wood, C. et Alvarez, M. (2005). *Emerging Construction Technologies*. A FIATECH catalogue; in Zhai, D., Goodrum, P.M., Haas, C.T., and Caldas, C.H. (2009). Relationship between Automation and Integration of Construction Information Systems and Labor Productivity. *Journal of Construction Engineering and Management*, 135(8), 746-753.

Woods, M., Taylor, L. et Cheng Ge Fang, Gloria (2012). Electronics: A Case Study of Economic Value Added in Target Costing. *Management Accounting Research*, 23(4), 261-277; in Vinten, G. (1994). Participant Observation: A Model for Organizational Investigation? *Journal of Managerial Psychology*, 9(2) 30-39.

Wing, C.K., Raftery, J. et Walker, A. (1998). The Baby and the Bathwater: Research Methods in Construction Management and Economics, 16(1), 99-104.

Yin, R.K. (2003). Case Study Research: Design and Methods, Sage, Thousand Oaks, CA, in Palsson, H. (2007). Participant Observation in Logistics Research. Experiences from an RFID Implementation Study. *International Journal of Physical Distribution & Logistics Management*. 37(2), 148-163.

Young, D.A.; Hass, C.T., Goodrum, P. et Caldas, C. (2011). Improving Construction Supply Networking Visibility by Using Automated Materials Locating and Tracking Technology. *Journal of Construction Engineering and Management*, 137(11), 976-984.

Zhai, D., Goodrum, P.M., Haas, C.T. et Caldas, C.H. (2009). Relationship between Automation and Integration of Construction Information Systems and Labor Productivity. Journal of Construction Engineering and Management, 135(8), 746-753.

Zhiliang, M.; Zhe, L. et Dongdong, Z. (2013). An Integrated Mobile Material Management System for Construction Sites. AEI, 353-362.

Zott, C. (2003). Dynamic Capabilities and the Emergence of Intra-industry Differential firm Performance: Insights from a Simulation Study. *Strategic Management Journal*, 24, 97-125; in Barreto, I. (2010). Dynamic Capabilities: A Review of Past Research and an Agenda for the Future. *Journal of Management*, 36(1), 256-280.

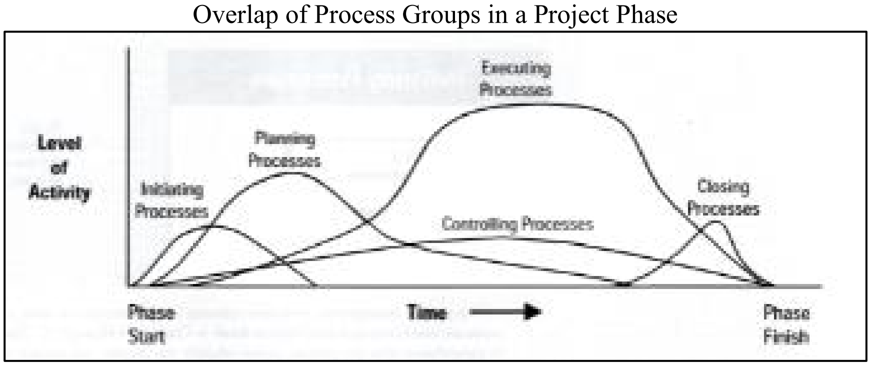
APPENDIX A

PMBOK

PROJECT MANAGEMENT BODY OF KNOWLEDGE

The Project Management Body of Knowledge (PMBOK) is a guide regarding planning, executing and controlling the operations of an organisation. PMBOK is overseen by the Project Management Institute (PMI). The project management phases presented in PMBOK are not discrete, one-time events, but are rather overlapping activities which occur at varying levels throughout each phase of the project. Figure A1 illustrates how the process groups overlap and vary within a phase.

Figure A. 1
Overlap of Process Groups in a Project Phase

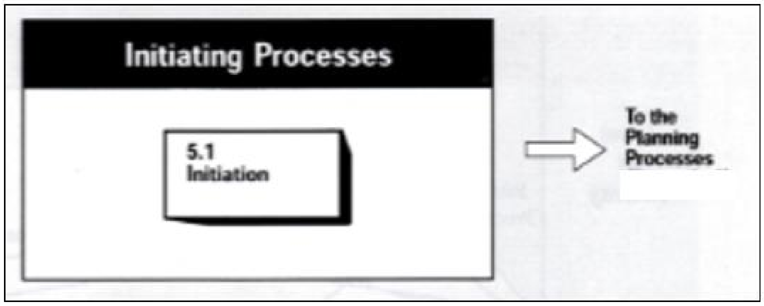


PMBOK (2011)

Figure A2 illustrates the Initiation Processes, committing the organization to begin the next phase of the project. Initiating the project, includes the following activities:

a. Conduct project selection methods;
b. Define the scope;
c. Document project risks, assumption and constraints;
d. Identify and performs stakeholder’s analysis;
e. Develop a project charter;
f. Obtain project charter approval.

Figure A. 2
Initiating Processes



PMBOK (2011)

The next process is the Planning Processes and is illustrated in Figure A3. Planning is one of the most important process to a project because it involves doing something new for the first time. Planning should commence with establishing the scope of the project. Planning includes the following activities:

a. Define and record requirements, constraints and assumptions;
b. Identify project team and define roles and responsibilities;
c. Create a Work Breakdown Structure (WBS);
d. Develop change management plan;
e. Identify risks and define risk strategies;
f. Obtain plan approval.

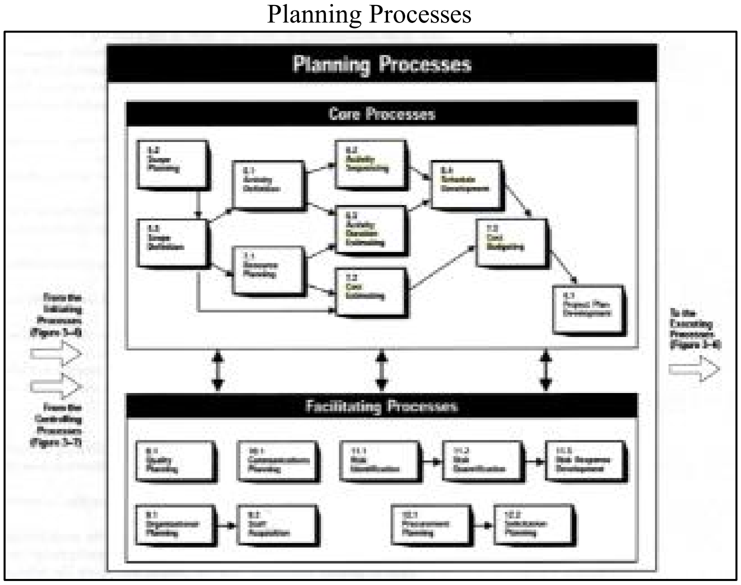
Planning processes are subject to frequent iterations prior to completing the plan. The core processes for planning include:

1. Scope Planning and Definition;
2. Activity Definition and Sequencing;
3. Activity Duration Estimating;
4. Schedule Development;
5. Resource Planning;
6. Cost Estimating and Budgeting;
7. Project Plan Development.

Then, the core processes of planning are supported by the facilitating processes, which include:

1. Quality Planning;
2. Organizational Planning;
3. Staff Acquisition;
4. Communication;
5. Risk Identification, Risk Quantification and Risk Response;
6. Procurement Planning;
7. Solicitation (Bid) Planning.

Figure A. 3
Planning Processes

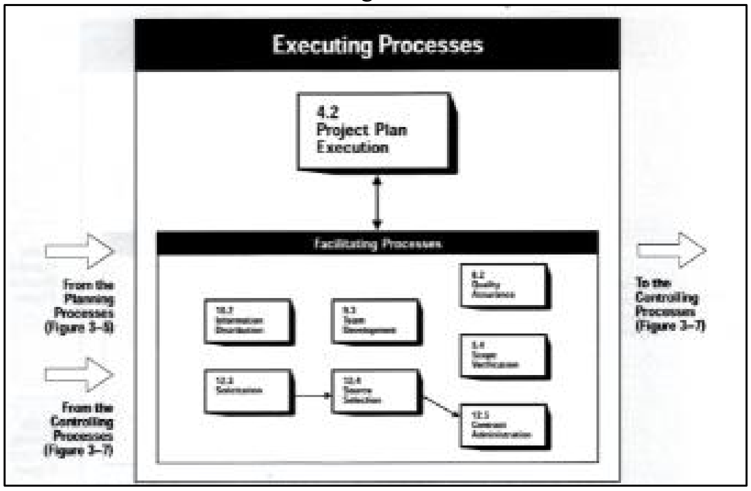


PMBOK (2011)

The Executing Processes include core processes and facilitating processes as described in Figure A4. The core process of planning processes is the Project Plan Execution and is facilitated through the following activities:

1. Scope Verification;
2. Quality Assurance;
3. Team Development;
4. Information Distribution;
5. Solicitations (Bid Selection);
6. Source Selection;
7. Contract Administration.

Figure A. 4
Executing Processes



PMBOK (2011)

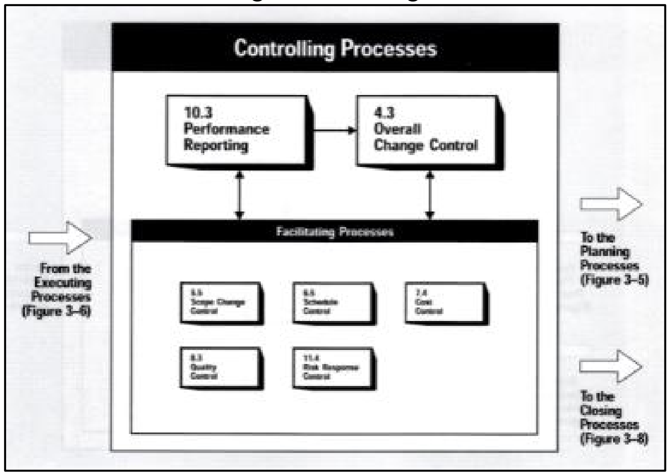
The Controlling & Monitoring Processes must be measured regularly to identify variances from the plan. Variances are fed into the control processes in the various knowledge areas. To the extent that significant variances are observed, adjustments to the plan are made by repeating the appropriate project planning processes. Controlling and monitoring also include taking preventive action in anticipation of possible problems, such as.

a. Measuring project performance;
b. Verifying and manage changes in project;
c. Ensuring project deliverables confirm to quality standards;
d. Monitoring risks.

The Controlling and Monitoring Processes contains core and facilitating processes as described in Figure A5 and they include the following activities:

1. Overall Change Control.
2. Scope Change Control.
3. Schedule Control.
4. Cost Control.
5. Quality Control.
6. Performance Reporting.
7. Risk Response Control.

Figure A. 5
Controlling & Monitoring Processes

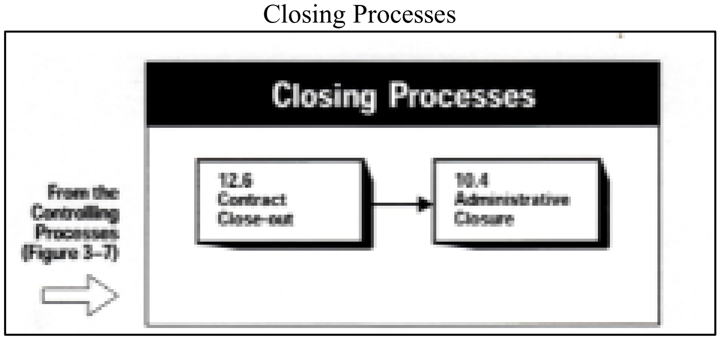


PMBOK (2011)

Finally, the Closing Processes end the project and it includes the following activities as illustrated in Figure A6:

a. Obtain final acceptance for the project;
b. Obtain financial, legal and administrative closure;
c. Release project resources;
d. Identify, document and communicate lessons learned;
e. Create and distribute final project report;
f. Archive and retain project records;
g. Measure customer satisfaction.

Figure A. 6
Closing Processes



PMBOK (2011)

APPENDIX B

CII / COAA

CII / COAA

In essence, the Construction Industry Institute (CII) and the Construction Owner Association of Albert (COAA), which are described in Figure B1, B2, and B3, the study of construction project management:

1. Scoping Study equates:

    - PMBOK's Initiation Processes;
    - Conceptual Phase in construction project management;
    - Level 1 schedule;
    - Operational process assets;
    - Permit applications;
    - Project risk register;
    - Preliminary flow diagram;

2. Design Basis Memorandum equates to similar phases to PMBOK's Planning Processes or Front-End Planning Phase in construction project management. For instance, the following activities are noted:

    a. Construction Management:

    - Level 2 schedule;
    - Project charter;
    - Project scope statement;
    - Project strategy;
    - Work Breakdown Structure;
    - Constructability plan;
    - Modularization and pre-assembly strategy;
    - Project Execution strategy;
    - Contracting strategy;
    - Construction execution strategy;
    - Heavy lift strategy;
    - Lessons learned.

    b. Engineering & Supply Chain

    - Process flow diagrams;
    - Site layout;
    - Long lead procurement;
    - Engineering delivery strategy;
    - Logistics strategy;

c. Operations, Commissioning and Start-Ups

- Systems Priority List;
- Commissioning & Start-ups Strategy.

3. Engineering Design Specifications equates to similar phases to PMBOK's Planning Processes or in Detailed-Engineering Phase in construction project management. For instance, the following activities are noted:

b. Construction Management:

- Level 3 schedule
- Project charter
- Project scope statement
- Project planning including Construction Work Package (CWP) schedule and FIWP release plan
- Constructability plan
- Modularization and pre-assembly plan
- Project Execution plan
- Contracting plan
- Construction execution plan
- Heavy lift plan
- Lessons learned

c. Engineering & Supply Chain

- Process flow diagrams;
- Site layout;
- Contracting plan;
- Long lead procurement;
- Engineering delivery plan, including Engineering Work Package (EWP).
- Logistics Plan.

d. Operations, Commissioning and Start-Ups

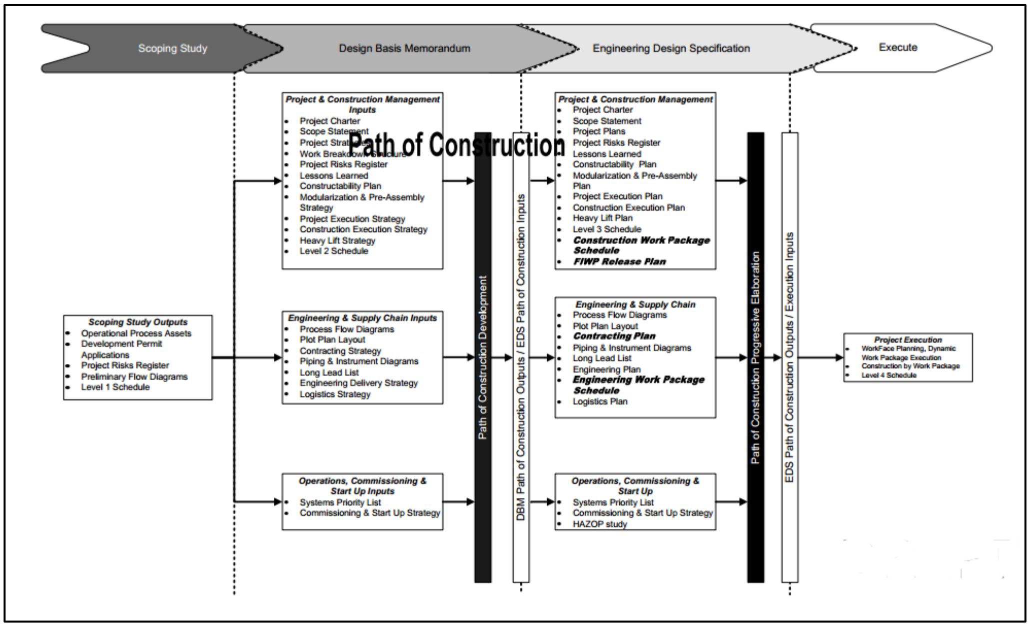
- Systems Priority List;
- Commissioning & Start-ups Strategy;
- HAZOP and Safety studies.

4. Execution equates to similar phases to PMBOK's Controlling & Monitoring and as well as the PMBOK's Execution. In terms of construction project management, this phase is named Construction. For instance, the following activities are noted:

- Level 4 schedule;
- Work-Face Planning;

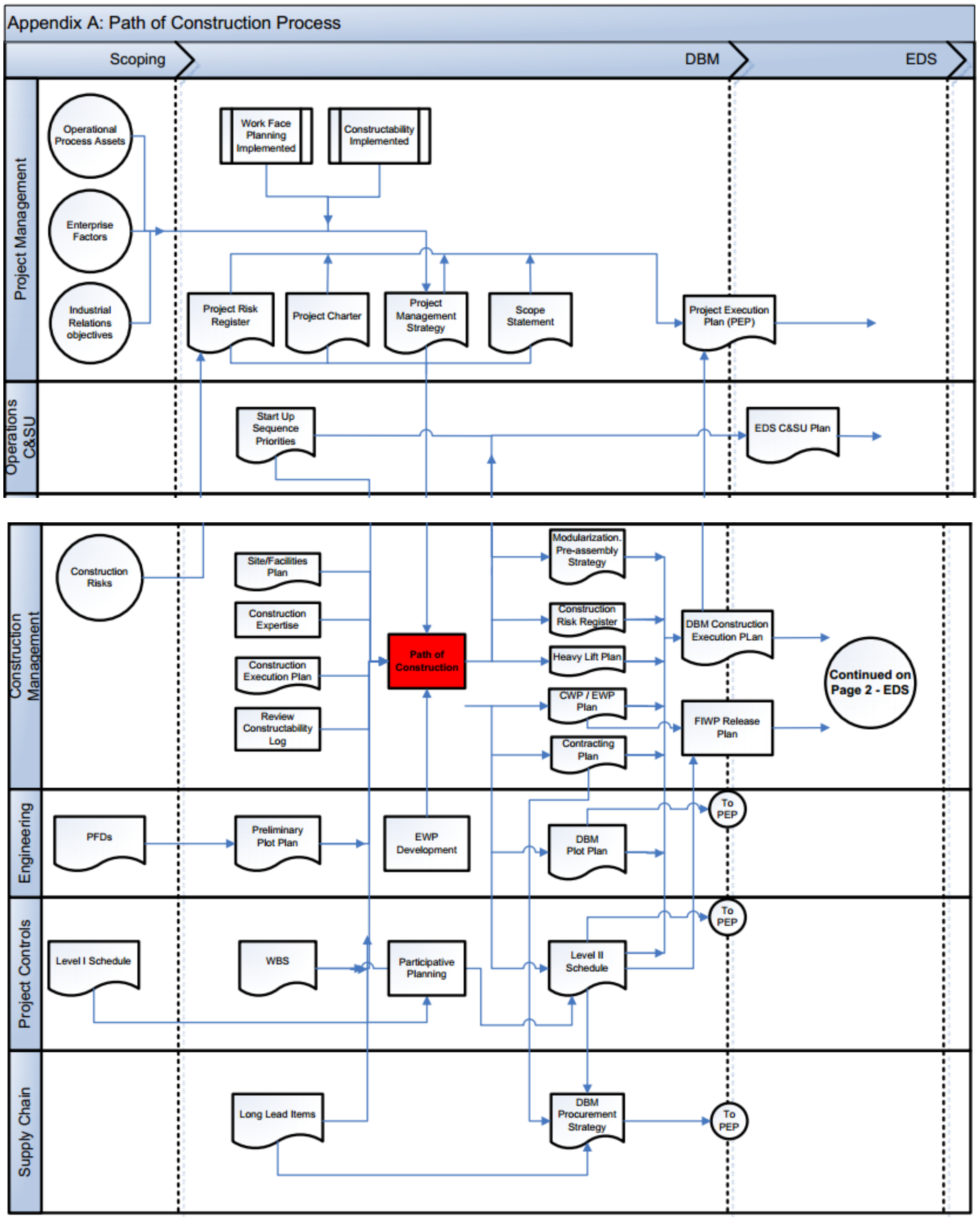
- Construction Work Package Execution;
- Productivity and performance reporting.

Figure B. 1
Path of Construction – Outlines



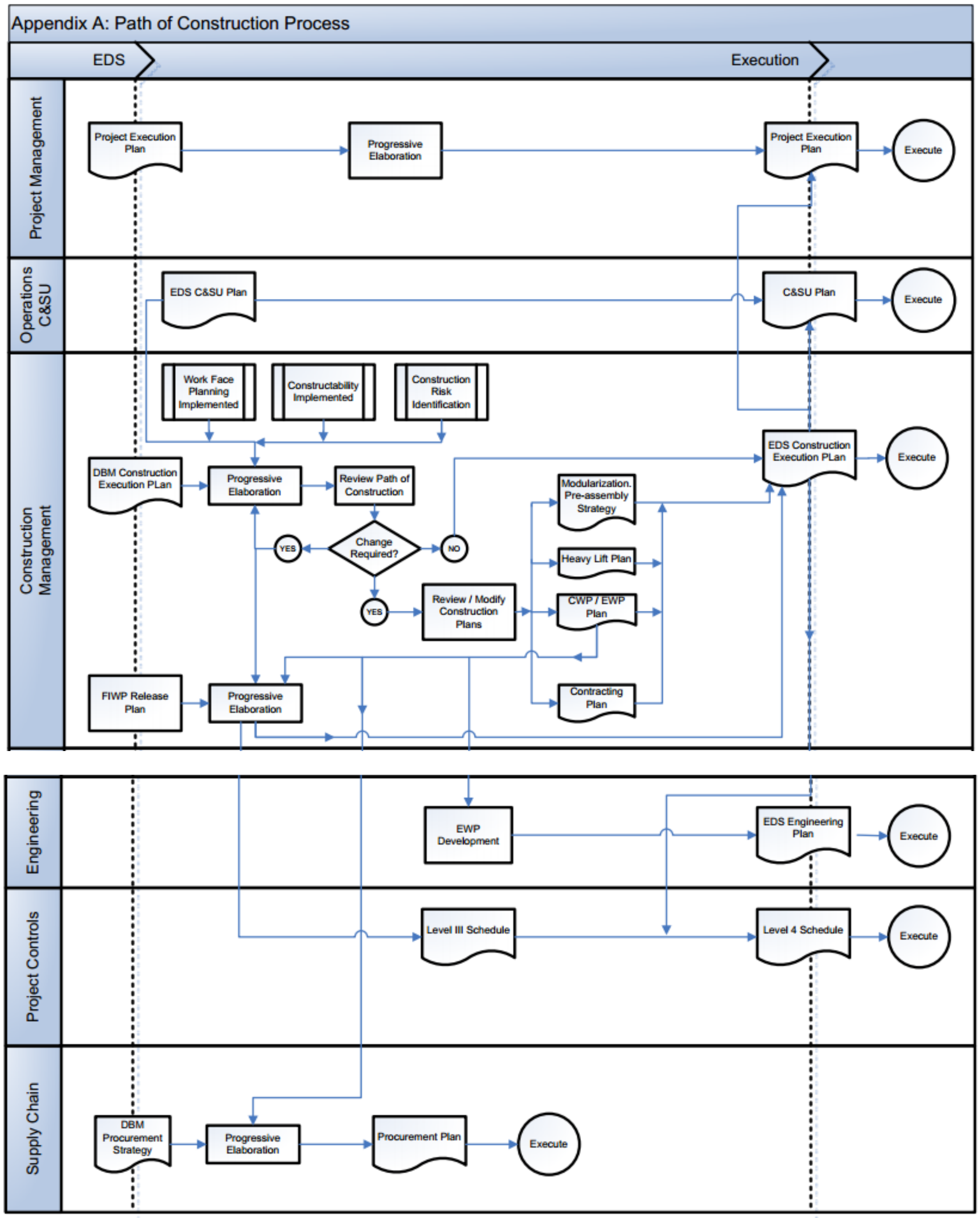
www.coaa.ab.ca/COAA-Library

Figure B. 2
Path of Construction Processes



www.coaa.ab.ca/COAA-Library

Figure B. 3
Path of Construction Processes



www.coaa.ab.ca/COAA-Library

APPENDIX C

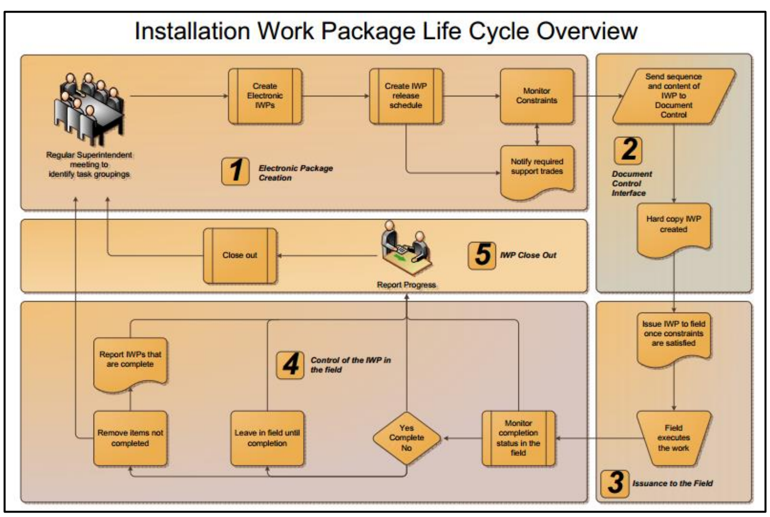
FIWP

FIELD INSTALLATION WORK PACKAGE

The information below is obtained from the Construction Owner Association of Alberta (COAA). Installation Work Packaging (IWP) represents a process incorporating the required communication, constraint checking/validation and final documentation that allows the ultimate customer and the crew at the work face, to successfully perform the prescribed work.

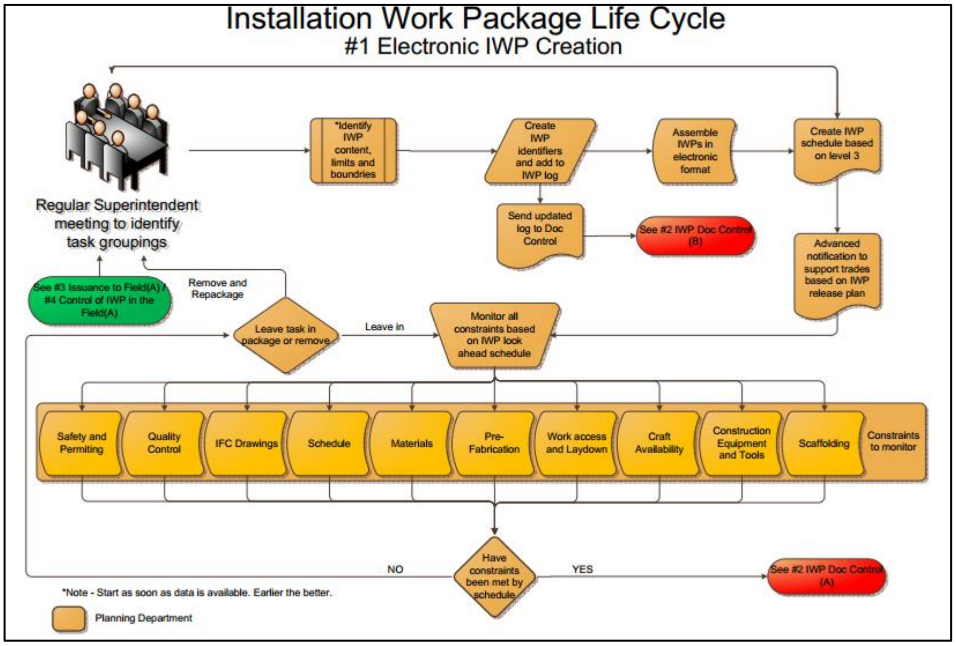
For Feld Installation Work Packaging (FIWP) to be effectively implemented, the IWP Life Cycle process is to follow five distinct activities; Electronic IWP Creation, Document Control Interface, Issuance of IWP to the Field, Control of the IWP in the Field and the IWP Close out. Each of five separate blocks in the overview contains key elements of the IWP life cycle. The blocks are numerated with ties to subsequent flow diagrams that further breakdown the essential IWP processes from creation, to document control, through issuance and control in the field, and, finally, to close out. The IWP lifecycle incorporates industry best practices and data recently compiled by members of this research team at active jobsites using a work packaging program.

Figure C. 1
COAA: IWP Lifecycle



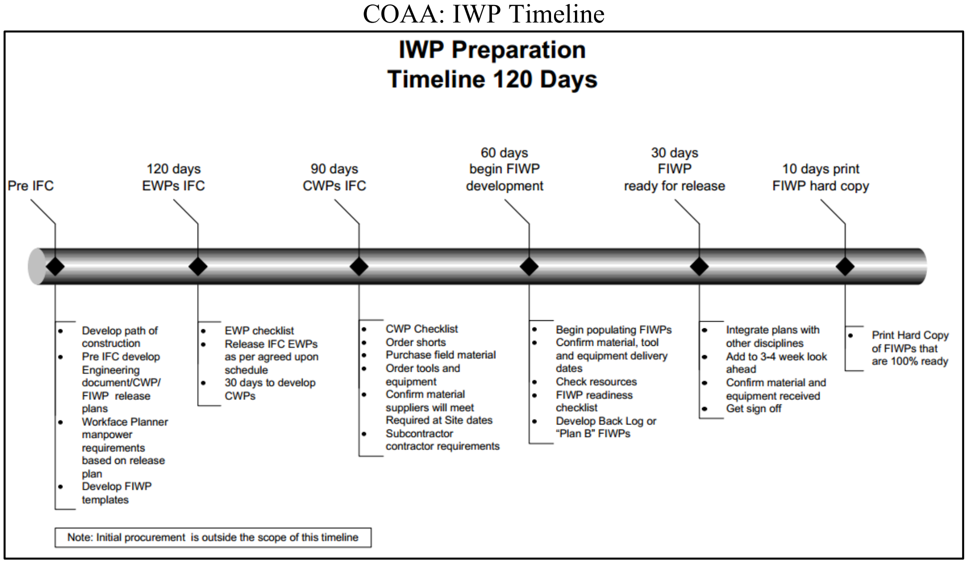
COAA WFP-WFS-2013-142-A

Figure C. 2
COAA: IWP Lifecycle



COAA WFP-WFS-2013-142-A

Figure C. 3
COAA: IWP Timeline



www.coaa.ab.ca/COAA-Library

APPENDIX D

CONSTRUCTION PERFORMANCE & PRODUCTIVITY MODEL

Figure D. 1
Construction Performance & Productivity Model

Construction Performance & Productivity Model

Project Phases	Construction Activities	SCOR Processes	Metho	Performance Attributes	Definitions	Level 1 Metrics	Level 2 Metrics	Level 3 Metrics
Pre- Construction: **1. Detailed Engineering** **2. Constructability** **Construction:** **3. Execution**	**Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Return**	Quantitative	**I. Procurement Reliability**	The performance of the Procurement Department in delivering the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct place (warehouse / laydown) customers. The ability to perform tasks as expected. Reliability focuses on the predicatbility of the outcome of a process.	1. Delivery Performance	1.1. Scheduled Purchase Orders Made by Owner's Request 1.2. Delivery Performance Against Owner's Requested Date 1.3. Delivery Performance by Suppliers' Committed Date 1.4. Perfect Orders' Fulfillment 1.5 Purchase Orders' Quality & Accuracy 1.6 Invoices' Accuracy	1.1: 10 metrics 1.2: 6 metrics 1.3: 5 metrics 1.4: 2 metrics 1.5: 7 metrics 1.6: 10 metrics Total: 40 metrics
Pre- Construction: **1. Detailed Engineering** **2. Constructability** **Construction:** **3. Execution**	**Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Return**	Quantitative	**II. Procurement Responsiveness**	The speed at which Procurement provides products to its Engineering / Construction Team. This is the average actual cycle time (days) consistently achieved to fulfill customer order. The speed at which tasks are performed during egngineering and construction phases. Typical metrics: Cycle Time	2. Purchase Order Fulfillment Cycle Time	2.1 Purchase Order Entry Completed 2.2 Invoice Received at Owner 2.3 Inquiry Time - Procurement	2.1: 5 metrics 2.2: 4 metrics 2.3: 2 metrics Total: 11 metrics

Construction Performance & Productivity Model

Project Phases	Construction Activities	SCOR Processes	Metho	Performance Attributes	Definitions	Level 1 Metrics	Level 2 Metrics	Level 3 Metrics
Pre- Construction: **1. Conceptual Design** **2. Front-End Planning** **3. Detailed Engineering** **4. Constructability** **Construction:** **5. Execution** **6. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver** **Return**	Quantitative	**III. EPCM Agility**	The ability, flexibility and adaptability for the three "3" groups (Engineering, Procurement, Construction Management) to respond to external and internal influences, the ability to respond to changes, to maintain or improve the project's scope objectives (deliver on time, on budget and at the highest quality). **Typical metrics: Flexibility, Adaptability, Changes**	3. "E" Engineering 4. "P" Procurement 5. "CM" Construction Management	3.1 Engineering Changes 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks 3.5 Quality - NCR 4.1 Material Management 4.2 Transportation Management 4.3 Leased Equipment Availability 4.4 Inventory Management 4.5 Bagging / Expediting at Site 4.6 Reverse Logistics 5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning 5.5 Document Control 5.6 Information Technology 5.7 Contract & Labour 5.8 Health, Safety & Environment	3.1: 6 metrics 3.2: 4 metrics 3.3: 9 metrics 3.4: 4 metrics 3.5: 18 metrics 4.1: 19 metrics 4.2: 6 metrics 4.3: 3 metrics 4.4: 5 metrics 4.5: 4 metrics 4.6: 3 metrics 5.1: 12 metrics 5.2: 5 metrics 5.3: 23 metrics 5.4: 9 metrics 5.5: 2 metrics 5.6: 4 metrics 5.7: 8 metrics 5.8: 17 metrics Total: 161 metrics

Construction Performance & Productivity Model

Project Phases	Construction Activities	SCOR Processes	Metho	Performance Attributes	Definitions	Level 1 Metrics	Level 2 Metrics	Level 3 Metrics
Pre- Construction: **1. Conceptual Design** **2. Front-End Planning** **3. Detailed Engineering** **4. Constructability** **Construction:** **5. Execution** **6. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver** **Return**	Quantitative	**IV. Project Controls**	The cost associated with operating a Project. Typical metrics: Labor costs, Equipment & Material costs, Management costs.	6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends	6.1 Budget (Actual vs. EAC) 6.2 Earned & Burned Indicators 7.1 Labour & Management Spends 7.2 Material/ Equipment Spends 7.3 Rework Spends 7.4 IT Integration Spends 8.1 Transportation Spends 8.2 Customs Spends 8.3 Warehouse / Laydown Spends 8.4 Inventory Carrying Costs 9.1 Suppliers Spends 9.2 Purchase Order Costs	6.1 8 metrics 6.2 3 metrics 7.1 4 metrics 7.2 5 metrics 7.3 4 metrics 7.4 1 metrics 8.1 6 metrics 8.2 2 metrics 8.3 3 metrics 8.4 7 metrics 9.1 6 metrics 9.2 3 metrics Total = 52 metrics
Pre- Construction: **1. Detailed Engineering** **2. Constructability** **Construction:** **3. Execution**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)**	**Plan** **Source** **Made** **Deliver**	Quantitative	**V. Workers (Asset) Management**	The effectiveness of an organisation in managing its primary asset (Labor Force + Managerial Staffs) in order to maintain or improve the project's scope objectives (deliver on time, on budget and at the highest quality). Typical metrics: age, years of experience, trades, etc.	10. Workers' Information	10.1 Labour Force's Information 10.2 Management Information	10.1 13 metric 10.2 10 metric Total = 23 metrics

Construction Performance & Productivity Model								
Project Phases	**Construction Activities**	**SCOR Processes**	**Metho**	**Performance Attributes**	**Definitions**	**Level 1 Metrics**	**Level 2 Metrics**	**Level 3 Metrics**
Pre- Construction: **1. Front-End Planning** **2. Detailed Engineering** **3. Constructability** **Construction:** **4. Execution** **5. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver**	Quantitative & Qualitative	**VI. Project Complexity**	The complexity of a project is assessed along two dimensions (Off-Site and at Job-Site). High levels of project complexity, left unmanaged, reduce operational performance and lead to higher costs.	11. Off-Site Complexity 12. Job Site Complexity	11.1 Manufacturing Complexity 11.2 Distribution Complexity 11.3 Supplier Base Complexity 11.4 IT Base Complexity 12.1 Contractor Base Complexity 12.2 Management Team / Owner Representatives	11.1 2 metrics 11.2 9 metrics 11.3 3 metrics 11.4 5 metrics 12.1 47 metrics 12.2 13 metrics Total = 79 metrics
Pre- Construction: **1. Front-End Planning** **2. Detailed Engineering** **3. Constructability** **Construction:** **4. Execution** **5. Project Closed-Out**	**Engineering (Estimators, Scheduling, Planning, Engineers,)** **Procurement (Buyers, Logistics, Transportation, Customs, Warehousing, Materials)** **Construction (Scheduling, Planning, Engineers, Leads, Surveying, Quality), Commissioning)** **Management (Cost, Contract, Documentation, Safety)**	**Plan** **Source** **Made** **Deliver** **Return**	Qualitative	**VII. Project Integration**	The framework evaluates how well your project team is integrating the Performance Attributes into multiple phases (from conception to closed out) of the project. **Typical merics: Level 2 + 3 metrics & Project Flow Chart**	. Performance Analytic	14.1 Level I and Level II metrics' integration 14.2 Level II and Level III merics' Integration	366 metrics

Dany Julien (2019)

APPENDIX E1

PROJECT COST ANALYSIS

PROJECT COST ANALYSIS

In general, the Concept phase involves development of general project objectives and constraints. For instance, it will describe general type of plant, technical performance criteria, location, and order of magnitude of +/- 50% accuracy range in cost.

The design or detailed engineering phase expedite the completion of all designs to a minimum of 60% before the start of the construction phase. The long lead items during the design phase are worked with the engineers in the timely development of requisitions for specific equipment and materials. The order of cost magnitude during the design or detailed engineering phase hovers around +/-10 accuracy.

The construction, commissioning and closed-out phases involve detailed testing of the completed facilities with subsequent turnover to the operating personnel of the owner. The order of magnitude for costing during construction is targeted to be +/-5% accuracy.

There are other cost reporting techniques such as the PFS and the FS reports. The pre-feasibility (PFS) and feasibility (FS) studies involve the examination of a number of engineering, project execution and financing alternatives, resulting in preliminary version of the design, project schedule, capital cost estimate and contingency plans (Silver, 1988). In terms of magnitude, the pre-feasibility phase seeks a cost accuracy of +/-25%, whereas the feasibility phase further its accuracy with +/-15%. The execution phase, in this case, seeks +/-5% accuracy within budget.

APPENDIX E2

PROJECT FLOW CHART

PROJECT FLOW CHART

“see insert”

APPENDIX E3

PARTICIPANT OBSERVATIONS: CONCEPTUAL

PARTICIPANT OBSERVATIONS: CONCEPTUAL

Table E3. 1
Business Development

CONCEPTUAL PHASE		
Participation Observation at Engineering Firm		
No	**Business Development**	**SC Activity**
100	Market Research & Strategic Plan	No
111	Tracking & Reporting	Yes
100	Identify Prospect & Develop Project	No
100	Complete Bid / No Bid Evaluation	Yes
100	Receive Request For Proposal	Yes
100	Customer Follow-up	Yes
100	Fill Out Award Notification	Yes
141	Proposal Debrief	Yes
100	Close Out Proposal Work Order	Yes
143	Lessons Learned	No
100	Final Negotiation - Ops & B-D	Yes
111	Input Results Into Wins	Yes
100	Execute Prime Contract	Yes
	No of B&D Activities	13
	No of Supply Chain Activities	10
	% of Supply Chain Activities	77%

Dany Julien (2019)

Table E3. 2
Proposal Process

CONCEPTUAL PHASE		
Participation Observation at Engineering Firm		
No	**Proposal Process**	**SC Activity**
121	Assess Requirement / Proposal Budget	No
123	Establish Proposal Budget & Win Strategy	No
122/127	Complete Bid Authorization Form & ERC	Yes
100	Send Letter to Customer and Return RFP	Yes
123/126	Obtain Proposal Number & Distribute	Yes
124	Proposal Kick-Off Meeting	Yes
127	Proposal Review	Yes
127	ERC Review	No
100	Proposal Transmitted to Customer	Yes
100	Customer Follow-up	Yes
201	Preliminary Scope of Work	No
202	Preliminary Project Execution Plan	No
208	Safety & Health	No
207	Code Requirement Identified	No
211	Project Definition Rating	No
300	Develop & Issue Preliminary WBS	No
226	Preliminary Automation Plan	No
303	Contingency & Risk Analysis	No
480	Quality Plan	No
302	Develop & Issue Proposal Schedule	No
202	Preliminary Project Execution Plan	No
202	Develop Preliminary Engineering Package	No
202	Multi-Office Engineering Execution Plan	No
212	Risk Management Plan	No
400	Preliminary Material Take-Off	Yes
301	Supplier & Subcontractor Pricing	Yes
301	Sales, Taxes, Bond, Insurance	No
361	Engineering License	No
359	Budget Time & Cost for Engineering	No
364	Preliminary Permit, Approval List & Budget	No
301	Complete, Approve & Finalize Estimate	No
301	Review the Estimate	No
301	Prepare Estimate For Compliance	No
301	Establish Purpose, Viability & Reconcile	No
301	Receive Estimate Request	No
304	Develop Preliminary Cash Flow	No
310	Bid Quantity	No
	No of Proposal Activities	37
	No of Supply Chain Activities	9
	% of Supply Chain Activities	24%

Dany Julien (2019)

Table E3. 3
Conceptual Phase

CONCEPTUAL PHASE	
Participation Observation at Engineering Firm	
No of Conceptual Activities	50
No of Supply Chain Activities	19
% of Supply Chain Activities	38%

Dany Julien (2019)

APPENDIX E4

PARTICIPANT OBSERVATIONS: FRONT-END PLANNING

PARTICIPANT OBSERVATIONS: FRONT-END PLANNING

Table E4. 1
Preliminary Designs & Studies

FRONT-END PLANNING PHASE		
Participation Observation at Engineering Firm		
No	**Preliminary Designs & Studies**	**SC Activity**
202	Develop Project Execution Plan	No
212	Risk Management Plan	No
202	Engineering Execution Plan and CAE/CAD	No
202	Multi-Office Engineering Execution Plan	No
354	Develop Preliminary Material & Equipment	Yes
351	Define Data Requirements & Quality	No
351	Evaluate Data Against Objectives	No
351	Document Data Quality & Usability	No
362	Develop Project Study List	No
362	Perform Study & Prepare Report	No
362	Check Interdisciplinary Review	No
362	Issue Report for Approval	No
362	Customer & Regulatory Review	No
362	Issue Final Report	No
	No of Preliminary Designs & Studies Activities	14
	No of Supply Chain Activities	1
	% of Supply Chain Activities	7%

Dany Julien (2019)

Table E4. 2
Project Initiation & Planning

FRONT-END PLANNING PHASE		
Participation Observation at Engineering Firm		
No	**Project Initiation & Planning**	**SC Activity**
226	IT Automation Plan	No
210	Team Building Plan	No
201	Revise Scope of Work for Prime Contract	No
202	Develop (Start) Final Engineering Package	No
202	Multi-Office Execution Plan	No
202	Prepare CAD/CAE Execution Plan	No
206	Review Lessons Learned Database	No
208	Develop Project Safety Plan	No
209	Select Sofware Applications	No
300	Revise WBS Based on Contract SofW	No
302	Develop Master Schedule	No
312	Establish Baseline Budget	No
303	Contingency Management Plan	No
304	Revised Cash Flow	No
480	Quality Plan	No
316	Create Project Filing Index	No
317	Document Distribution Plan	No
202	Prepare Project Execution Plan	No
202	Review Approval & Distribution Plan	Yes
200	Initiation Checklist & Schedule	No
705	Employee Training & Development	No
754	Recruiting & Selection	No
200	Project Kick-Off Meeting	No
202	Project Team Package Training	No
200	Obtain Insurance Certificates & Bonds	No
200	Execute Confidentiality Agreements	No
212	Risks & Opportunity Assessment	No
200	Contract Data Sheet & Billing Instruction	No
200	Company Letter of Instruction to PM	No
200	Prepare Contract Briefing	No
450	Site Layout & Drainage Plan	Yes
451	Review Checkilist & Mobilization Plan	Yes
207	Prepare Code Search	No
364	Regulatory Compliance Plan Review	No
361	Regulatory Compliance Plan iaw Engineering	No
207	Id Licenses, Permits, Codes, HAZMAT, etc.	No
207	Business License	No
482	Quality Survey	No
202	Develop Project Procurement Plan	Yes
	No of Project Initiation & Planning Activities	39
	No of Supply Chain Activities	4
	% of Supply Chain Activities	10%

Dany Julien (2019)

Table E4. 3
Project Communication, Document Control, Distribution

FRONT-END PLANNING PHASE		
Participation Observation at Engineering Firm		
No	**Project Communication, Doc Control, Distribution**	**SC Activity**
316	Establish & Maintain Project File	No
317	Document Control & Distribution	No
319	Incoming Emails, IOC, Drawings, etc.	No
317	Copy to Document Control	No
319	Emails, Fax Communication	No
317	Logged	No
317	Distributed	No
319	Incoming Documents	No
317	Logged	No
317	Distributed on a Transmittal Letter	No
317	Logged	No
319	Outgoing Communications	No
319	Signed by Project Manager	No
317	Document Control	No
317	Logged	No
317	Distribution	No
319	Meeting Minutes	No
317	Distributed	No
316/317	Field per Records Retention Coding	No
	No of Comm, Doc Control & Distribution Activities	19
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E4. 4
Front-End Planning Phase

FRONT-END PLANNING PHASE	
Participation Observation at Engineering Firm	
No of Front-End Planning Activities	72
No of Supply Chain Activities	5
% of Supply Chain Activities	7%

Dany Julien (2019)

APPENDIX E5

PARTICIPANT OBSERVATIONS: FEP & DE

PARTICIPANT OBSERVATIONS: FEP & DE

Table E5. 1
Planning & Scheduling

FRONT-END PLANNING & DETAILED ENGINEERING PHASES		
Participation Observation at Engineering Firm		
No	**Planning & Scheduling**	**SC Activity**
302	Develop Resource Loading	No
302	Track Actual Progress	No
302	Prepare Look-Ahead Schedules	No
302	Maintain the Master Schedule	No
302	Prepare Schedule Analysis	No
	No of Planning & Scheduling Activities	5
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E5. 2
Progress & Performance Measurement

FRONT-END PLANNING & DETAILED ENGINEERING PHASES		
Participation Observation at Engineering Firm		
No	**Progress & Performance Measurement**	**SC Activity**
305/306	Develop & Issue Time Charging List	No
305/306	Develop Progressing Task List	No
305/306	Monitor Progress and Update Monthly	No
307/308	Generate Report Calendar	No
307/308	Prepare the Report	No
307/308	Distribute the Report	No
307/308	Review Project Status Monthly	No
307/308	Action Items Identified	No
	No of Progress & Performance Activities	8
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E5. 3
Customer Satisfaction

FRONT-END PLANNING & DETAILED ENGINEERING PHASES		
Participation Observation at Engineering Firm		
No	**Customer Satisfaction**	**SC Activity**
701	Customer Request to Participate in CS Evaluation	No
701	Evaluate Project Performance Against Goals	No
701	Survey Conducted	No
701	Customer Complaint	No
701	Review & Develop Action Plan	No
701	Resolve Complaint	No
701	Id Major Issues in the Internal Project Status Report	No
701	Review with Business Development & Management	No
	No of Customer Services Activities	8
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E5. 4
Change Control

FRONT-END PLANNING & DETAILED ENGINEERING PHASES		
Participation Observation at Engineering Firm		
No	**Change Control**	**SC Activity**
314	RFI	No
314	Potential Change Identified	No
314	Internal Change	No
314	Review and Evaluate Change	No
314	Change to Prime Contract	No
314	Assess Impact to Cost and Schedule	No
314	Notify Customer	No
314	In-House Review & Approval	No
314	Customer Review for Prime Contract Change	No
314	Disapprove - no action required	No
314	Update Cost Baseline and Master Schedule	No
314	Implement Change in Field	No
314	Revise Engineering & Procurement Documents	No
	No of Change Control Activities	13
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E5. 5
Administration, Invoicing, Account Payable

FRONT-END PLANNING & DETAILED ENGINEERING PHASES		
Participation Observation at Engineering Firm		
No	**Administration, Invoicing, Account Payable**	**SC Activity**
303	Develop Contingency Drawdown Curve	No
303	Monitor & Report Contingency Drawdown	No
320	Provide Construction Payroll	No
320	Monitor & Verify Accuracy of the Financial System	No
320	Produce Monthly Revenue Recognition Calculations	No
320	Justify Contingency and Reserves	No
320	Produce Monthy Financial Forecasts	No
320	Develop Billing Strategy	No
321	Labor Charges	No
321	Project Billing	No
321	Draft Invoice	No
321	Supplier & Subcontractor Invoices	No
321	Verify the Invoice Against the PO, CA, and Receiver	No
321	Project Approval For Payment	No
321	Shared Services Accounts for Payment	No
321	Employee Expenses	No
321	Reimburse Employee	No
321	Pay Supplier or Subcontractor per Terms	No
313	Review & Approval	No
313	Submit to Customer	No
313	Review Accounts Receivable Report	No
313	Follow-up to Obtain Late Payments	No
	No of Admin., Invoice, Account Payable Activities	22
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E5. 6
Financial Reporting, Cost Analysis, Forecasting

FRONT-END PLANNING & DETAILED ENGINEERING PHASES		
Participation Observation at Engineering Firm		
No	**Financial Reporting, Cost Analysis & Forecasting**	**SC Activity**
320	Produce Monthy Financial Forecasts	No
320	Monthly Insurance Report	No
320	Prepare Tax Report	No
320	Review & Approval of Final Estimate at Completion	No
700	Calculate Financial Metrics	No
700	Feed Corporate Management System	No
700	Analye Variances	No
700	Determine Cuase and Corrective Action	No
700	Report to Project, Division, Business Unit & Corp.	No
304	Prepare Monthly Update of Cash Flow	No
312	Accumulate Monthly Data on Acutal Costs & Commit.	No
312	Monthly Cost Analysis, Schedule, Earned & Actual	No
312	Periodic Forecast Analysis	No
312	Prepare Etimate	No
	No of Finance, Costs Analysis, Forecasting Activities	14
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E5. 7
Front-End Planning & Detailed Engineering Phases

FRONT-END PLANNING & DETAILED ENGINEERING PHASES	
Participation Observation at Engineering Firm	
No of Front-End Plan. + Detailed Engin. Activities	70
No of Supply Chain Activities	0
% of Supply Chain Activities	0%

Dany Julien (2019)

APPENDIX E6

PARTICIPANTS OBSERVATIONS: DETAILED ENGINEERING

PARTICIPANTS OBSERVATIONS: DETAILED ENGINEERING

Table E6. 1
Detailed Design

DETAILED ENGINEERING PHASE		
Participation Observation at Engineering Firm		
No	**Detailed Design**	**SC Activity**
364	Compliance Review Plan & Permits	No
364	Contact with Regulatory Agencies	No
364	Identify Design Information	No
350	Prepare Design Basis Document	No
350	Internal Review	No
350	Customer Review & Approval	No
350	Distribute to Team per Document Distribution Plan	No
363	Process Hazards Analysis	Yes
358	Prepare Drawings	No
365	Constructabiltiy Review	Yes
358	Discipline Check	No
358	Issue Drawings For Budget, Quotes, Bidding, Mgmt.	No
358	Inter-Discipline Review	Yes
359	Chief Design Engineer Review	No
358	Customer Review	No
358	Final Sign-Off, Seal	No
358	Approved & Issued Drawings for Construction	No
364	Develop and Submit Permit Applications or Variance	No
364	Agency Review Approval	No
357	Prepare Data Sheet	No
357	Discipline Review	No
357	Inter-Discipline Review	Yes
357	Review by Customer	No
357	Verify Sign-Off and Seal	No
355	Approved and Issues Data Sheets for Bids	Yes

352	Identify Equipment & Devices by Disciplines	Yes
352	Establish Tag Numbers iaw Discipline Guideline	No
354	Create & Maintain Equipment & Instrument List	Yes
353	Identify Required Design Documents	No
353	Establish Design Documents Numbering System (WBS)	No
360	Technical Software Selection, Validation and Control	No
356	Prepare Calculation	No
356	Calculation Checked	No
356	Finalize and Release Calculations	No
353	Create & Maintain Design Documents	No
353	Prepare Specifications	Yes
355	Dicipline Review	No
355	Inter-Discipline Review	No
355	Review by Quality, Construction, Procurement, Start-up	Yes
355	Resolve Comments	Yes
355	Customer Review	No
355	Approved & Issued Specifications for Construction	No
355	Approved & Issued Specifications for Bids	Yes
401	Prepare Technical Requisition	No
401	Discipline Review	No
401	Quality Review	No
401	Approval & Issue for Obtaining Quote	Yes
400	Material Take-Off	Yes
	No of Detailed Design Activities	49
	No of Supply Chain Activities	13
	% of Supply Chain Activities	27%

Dany Julien (2019)

Table E6. 2
Purchasing Process

DETAILED ENGINEERING PHASE		
Participation Observation at Engineering Firm		
No	**Purchasing Process**	**SC Activity**
402	Prepare Request for Quotation	Yes
402	Complete Single Source Justification & Obtain Approval	Yes
402	Complete Authority for Expenditure & Obtain Approval	Yes
402	Include General Conditions for PO of $200K or Less	Yes
704	Legal Review	Yes
402	Include General Conditions for PO of $200K or More	Yes
402	Issue Request for Quotation (RFQ)	Yes
403	Establish Review Criteria	Yes
402	Receives Bids and Completes Commercial Bid Form	Yes
403	Review Proposal & Prepare a Technical Evaluation Form	Yes
402	Manage Communication, Meetings, Changes in Bid Cycle	No
402	Prepare RFQ Addendum	Yes
402	Prepares Bid Analysis Summary & Obtain Approvals	Yes
402	Prepare and Issue PO	Yes
405	Coordinate & Expedite Receipt of Vendor Data	Yes
310	Purchase Quantity	Yes
	No of Purchasing Process Activities	16
	No of Supply Chain Activities	15
	% of Supply Chain Activities	94%

Dany Julien (2019)

Table E6. 3
Subcontracting Process

DETAILED ENGINEERING PHASE		
Participation Observation at Engineering Firm		
No	**Subcontracting Process**	**SC Activity**
406	Preparation of Subcontract Scope of Work	No
407	Finalize Bidders List & Obtain Approvals	Yes
407	Prepare & Issue Requistion Form	Yes
407	Prepare Request For Quotation	Yes
402	Complete Single Source Justification & Obtain Approval	Yes
407	Utilize Short Form Agreement & General Conditions	Yes
407	Utilize Agreement 407-20	Yes
704	Legal Review	No
407	Prepare RFP Addendum	Yes
407	Receives Bids and Completes Commercial Bid Form	Yes
403	Review Proposal & Prepare a Technical Evaluation Form	Yes
407	Prepares Bid Analysis Summary & Obtains Approvals	Yes
407	Prepare & Issue Subcontract	Yes
407	Ensure Bonds, Letters of Credit or Waivers Received	Yes
407	Pre-Construction Meeting	Yes
	No of Subcontracting Activities	15
	No of Supply Chain Activities	13
	% of Supply Chain Activities	87%

Dany Julien (2019)

Table E6. 4
Vendor Data Review Process

DETAILED ENGINEERING PHASE		
Participation Observation at Engineering Firm		
No	**Vendor Data Review Process**	**SC Activity**
482	Quality Review	No
404	Consolidate Comments, Mark Status Log & Distribute	No
404	Discipline & Customer Review	No
404	Log-In, Date Stamp & Distribute Vendor Data	No
404	Released for Fabrication with Certified Drawings	No
404	Final - No Return Required	No
404	Return Transmittal Only to the Supplier	Yes
404	With Comments, Relase for Fabrication	Yes
404	Not Release for Fabrication, Revised & Resubmit	No
404	Return Vendor Data to Supplier for Revision	Yes
404	Received Certified Data Vendor	Yes
	No of Vendor Data Review Activities	11
	No of Supply Chain Activities	4
	% of Supply Chain Activities	36%

Dany Julien (2019)

Table E6. 5
Labour Relation Process

DETAILED ENGINEERING PHASE		
Participation Observation at Engineering Firm		
No	**Labour Relation Process**	**SC Activity**
703	Comply with Industrial Relation Policy Manual	No
703	Pre-Job Conference	No
703	Jurisdictional Work Assigments	No
703	Secure Labour Through Union Halls	No
703	Construction Labour Relations Inspection Checklist	No
703	Absentee and Turnover Reports	No
	No of Labour Relation Process Activities	6
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E6. 6
Detailed Engineering Phase

DETAILED ENGINEERING PHASE	
Participation Observation at Engineering Firm	
No of Detailed Engineering Activities	97
No of Supply Chain Activities	45
% of Supply Chain Activities	46%

Dany Julien (2019)

APPENDIX E7

PARTICIPANT OBSERVATIONS' RESULTS: CONSTRUCTION

PARTICIPANT OBSERVATIONS: CONSTRUCTION

Table E7. 1
Information Technology

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Information Technology**	**SC Activity**
702	Identify Required Project Hardware & Software	No
702	Provide Procurement, Admin, Maintenance & Support	Yes
702	Perform Periodic System Backups	No
	No of Information Technology Activities	3
	No of Supply Chain Activities	1
	% of Supply Chain Activities	33%

Dany Julien (2019)

Table E7. 2
Field Submittal Control

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Field Submittal Control**	**SC Activity**
402/407	Review Subcontractor / Vendor Submittal Schedule	No
402/407	Receive and Log Submittal	No
402/407	Distribute Submittal to Appropriate Approver	No
426	Track Status of Submittal and Location	No
402/407	Revise and Resubmit	No
	No of Fied Submittal Control Activities	5
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E7. 3
Quality Surveillances Subcontracted Work

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Quality Surveillances Subcontracted Work**	**SC Activity**
481	Conduct Pre-Construction / Pre-Activity Meeting with Su	No
481	Conduct Periodic Quality Surveillances of Subcontractor	No
481	Conduct Follow-up Surveillance to Verify Correction / De	No
	No of Quality Surveillane Sub Work Activities	3
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E7. 4
Non-Conformances

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Non-Conformances**	**SC Activity**
457	Non-Conforming Product Identified	No
457	Tag or Segregate Product to Avoid Inadvertent Use	Yes
457	Prepare a Non-Conformance Reprot	No
300	Obtain a Cost Account Number	No
457	Assign NCR and Track Through NCR Log	No
457	Determine Disposition of the NCR	No
457	NCR Work Completed	No
457	Close NCR	No
	No of Non-Conformance Activities	8
	No of Supply Chain Activities	1
	% of Supply Chain Activities	13%

Dany Julien (2019)

Table E7. 5
Request for Information

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Requests for Information**	**SC Activity**
456	Questions Pertaining to Project Documents	No
456	Prepare a Request for Information (RFI)	No
456	RFI Log	No
456	Transmit the RFI to the Appropriate Party	No
456	Review and Respond	No
456	Log RFI Respond	No
	No of Requests for Information Activities	6
	No of Supply Chain Activities	1
	% of Supply Chain Activities	17%

Dany Julien (2019)

Table E7. 6
Field Engineering

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Field Engineering**	**SC Activity**
461	Field Change Request	No
460	Establish Horizontal & Vertical Control	No
	No of Field Engineering Activities	2
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E7. 7
Inspection, Testing & Test Equipment

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Inspection, Testing & Test Equipment**	**SC Activity**
483	Final Inspections	No
483	Special Processes Inspections & Tests	No
483	In-Process Inspections	No
483	Testing	No
458	Verify Calibration Certificate	No
458	If Cal Certificate Missing - Calibrate the Equipment	No
458	Tag Equipment with ID # and Calibration Expiration Date	Yes
458	Complete & Maintain the Inspection, Measuring and Test	No
458	Recalibrate Equipment at Specifiy Interval	No
	No of Inspection, Testing & Test Equipment Activities	9
	No of Supply Chain Activities	1
	% of Supply Chain Activities	11%

Dany Julien (2019)

Table E7. 8
Mechanical Completion

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Mechanical Completion**	**SC Activity**
459	Define System Boundaries and Completion Dates	No
459	Develop a Component List of Each System	No
459	Coordinate Completion Activities iaw the Schedule	No
459	Perform Final Inspections	No
459	Turnover Package with O&M Manual, Inspection and Te	No
459	Obtain Certificate of Final Acceptance from the Customer	No
452	Obtain Equipment Inspection & Maintenance Records	No
452	Inspect & Record Condition of Equipment	Yes
452	Prepare and Maintain an Equipment Rental Schedule	Yes
452	Review Euqipment Needs Periodcally	No
452	Assign Qualified Operator	No
452	Inspect Condition and Document Prior to Returning	No
	No of Mechanical Completion Activities	12
	No of Supply Chain Activities	2
	% of Supply Chain Activities	17%

Dany Julien (2019)

Table E7. 9
Tool & Equipment Control

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Tool & Equipment Control**	**SC Activity**
452	New Hire Signs Tool Agreement Form	No
452	Tool Issued to Employee for the Day	No
452	Create/Maintain Tool & Equipment Master Inventory Lo	Yes
452	Implement Inventory Control System	Yes
452	Tools Issued to Foreman For Extended Periods	No
452	Tools Returned and Noted in the Control System	No
452	Tool Loss Noted on the Lost Tool Report	No
	No of Tool & Equipment Control Activities	7
	No of Supply Chain Activities	2
	% of Supply Chain Activities	29%

Dany Julien (2019)

Table E7. 10
Field Order Process

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Field Order Process**	**SC Activity**
453	Daily Construction and Force Report	No
409	Urgent Field Change Identified	No
409	Prepare Field Order (FO)	No
409	Log & Track For Status	No
409	Obtain PM & Customer Approval	No
409	Issue to Subcontractor to Initiate Work & Pricing	No
409	Receive Subcontractor Price	No
409	Negotiate Final Price	No
301	Prepare Estimate	No
409	Obtain PM & Customer Approval	No
	No of Field Order Process Activities	10
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E7. 11 Safety

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Safety**	**SC Activity**
208	Implement Substance Abuse Program	No
208	Establish Medical & First Ad Service	No
208	Implement Safety Awards & Activities	No
208	Implement Security & Badging	No
208	Implement Safety Training & Communictions	No
208	Conduct Safety Hazards Analysis	No
208	Monitoring & Inspections of Work Activities	No
208	Conduct Accident & Incident Investigations	No
208	Monthly Reporting & Statistics	No
208	Document Safety Violations	No
	No of Safety Activities	10
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E7. 12
Progress & Safety Photographs

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Progress & Safety Photographs**	**SC Activity**
454	Photo or Video Tape Construction Progress Weekly	No
454	Identify and Log Photos and Videos	No
454	Photo or Video Tape Safety Related Incidents Violations	No
454	Identify and Log Photos and Videos	No
	No of Progress Safety Photographs Activities	4
	No of Supply Chain Activities	0
	% of Supply Chain Activities	0%

Dany Julien (2019)

Table E7. 13
Back Charges

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Backcharges**	**SC Activity**
408	Establish Backcharges Overhead and Profit Rates	No
408	Notify Supplier or Subcontractor	Yes
408	Negotiate Disposition with the Supplier / Subcontractor	Yes
408	Complete the Backcharge Agreement Form	No
408	Prepare & Maintain a Backcharge Log	No
408	Perform Repair Work or Replace Material	Yes
408	Track Costs	No
408	Notify Supplier or Subcontractor of Costs	Yes
408	Deduct Amount of Backcharge from Invoice	No
	No of Backcharges Activities	9
	No of Supply Chain Activities	4
	% of Supply Chain Activities	44%

Dany Julien (2019)

Table E7. 14
Construction Equipment, Process Equipment & Materials

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	Construction Equipment, Process Equipment & Materials	SC Activity
482	Source Inspections	No
405	Monitor Fabrication Process	No
405	Monitor Material & Equipment Delivery Process	Yes
410	Equipment or Material Arrives at Site	Yes
310	Received Quantity	Yes
	No of Construction Equipment, Process Equipment Activities	5
	No of Supply Chain Activities	3
	% of Supply Chain Activities	60%

Dany Julien (2019)

Table E7. 15
Mobilize

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	Mobilize	SC Activity
451	Review Mobilization Checklist	Yes
451	Prepare a Site-Specific Mobilization Plan	Yes
227	IT Project Mobilization	Yes
451	Execute Mobilization Plan	Yes
301	Estimating Support	Yes
	No of Mobilize Activities	5
	No of Supply Chain Activities	5
	% of Supply Chain Activities	100%

Dany Julien (2019)

Table E7. 16
Demobilize

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	Demobilize	SC Activity
451	Review Demobilization Checklist	Yes
451	Prepare a Site Specific to Demobilzation Plan	Yes
451	Execute the Demobilization Plan	Yes
	No of Demobilize Activities	3
	No of Supply Chain Activities	3
	% of Supply Chain Activities	100%

Dany Julien (2019)

Table E7. 17
Material Receipt & Warehousing

CONSTRUCTION PHASE		
Participation Observation at Engineering Firm		
No	**Material Receipt & Warehousing**	**SC Activity**
410	Note of Packing Slip - Receipt Inspection Not Performed	Yes
410	Material or Equipment Tagged "Not Receipt Inspected"	Yes
410	Records Equipment or Materials Installed, Not Inspected	Yes
410	Released for Consruction or Installation	Yes
482	Source Inspection	No
410	Check Against PO, OUSD, Packing List, Tagging	Yes
410	Prepre OSD Report	Yes
410	Photograph or Video Tape Damage	Yes
457	Prepare a Non-Conformance Report (NCR)	Yes
410	Notify Superintendent & Determine Drop Off Point	Yes
410	Sign Acceptance on Packing List	Yes
410	Document Receipt on Daily Receiving Register	Yes
412	Establish Wareohouse & Laydown Areas	Yes
412	Divide and Tag Storage Areas	Yes
413	Scrap and Surplus Material	Yes
413	Obtain Competitive Bids	Yes
413	Execute Sales Agreement	No
414	Material or Equipment Itemized on Outshipment Report	Yes
414	Prepare Outshipment Disclaimer Form	Yes
414	Note the Outshipment on the Outshipment Report	Yes
413	Develop / Maintain Surplus List	Yes
413	Determine Disposition	Yes
413	Negotiate Sale to Customer	No
413	Negotiate Price for Transfer to Another Company Project	No
413	Negotiate Price and Restocking Fees with Supplier	No
412	Determine Required Maintenance	Yes
412	Prepare Permanent Equipment Maintenance Record	Yes
412	Perform Required Maintenance	No
412	Maintain Record of Maintenance Performed	Yes
	No of Material Receipt & Warehousing Activities	29
	No of Supply Chain Activities	23
	% of Supply Chain Activities	79%

Dany Julien (2019)

Table E7. 18
Construction Phase

CONSTRUCTION PHASE	
Participation Observation at Engineering Firm	
No of Construction Activities	130
No of Supply Chain Activities	46
% of Supply Chain Activities	35%

Dany Julien (2019)

APPENDIX E8

PARTICIPANT OBSERVATIONS: CLOSED-OUT

PARTICIPANT OBSERVATIONS: CLOSED-OUT

Table E8. 1
Project Closed-Out Report

CLOSED-OUT PHASE		
Participation Observation at Engineering Firm		
No	**Project Closed-Out Report**	**SC Activity**
316	Prepare File for Archiving	No
316	Transfer Files to the Company Warehouse for Retention	Yes
318	Electronic Data Management	No
407	Close Out Subconcontract	No
	No of Project Closed-Out Report Activities	4
	No of Supply Chain Activities	1
	% of Supply Chain Activities	25%

Dany Julien (2019)

Table E8. 2 Closed-Out Phase

CLOSED-OUT PHASE	
Participation Observation at Engineering Firm	
Project Closed-Out Report	
No of Closed-Out Activities	4
No of Supply Chain Activities	1
% of Supply Chain Activities	25%

Dany Julien (2019)

APPENDIX F1

E&I ELECTRICAL CABLES

E&I ELECTRICAL CABLES

Original documents for the results for the Action Research contain three (3) pages under the code 1.1. EI Electrical Cable. Only one (1) partial page of data is inserted below, for display purposes.

Table F1. 1
E&I Electrical Cable

Reel #	Contractor Qty	CMT Qty	Cable Type	Conductor Size	No. of Conductors	Voltage	Description	$ / unit	Contractor $	CMT $	Date Counted	Location
469	150	150	BX	# 14	3	300 V	BX 3 C 14	$ 1.68	$ 252.00	$ 252.00	Oct.13.2015	Hill lay down, row 6
	0	100	BX	# 14	3	300 V	BX 3 C 14	$ 1.68	$ -	$ 168.00	Oct.13.2015	Hill lay down, row 6
	0	20	BX	# 12	2	300 V	BX 2 C 12	$ 1.68	$ -	$ 33.60	Oct.13.2015	Hill lay down, row 6
	0	75	BX	# 140	2	300 V	BX 2 C 04	$ 1.68	$ -	$ 126.00	Oct.13.2015	Hill lay down, row 6
131	0	75	Tech 90	# 16	12	600 V	Tech 90, XLPE/PVC AIA (Blue)	$ 1.91	$ -	$ 143.25	Oct.10.2015	Hill lay down, row 23
135	0	200	Tech 90	# 16	2	600 V	Tech 90,XLPE/PVC AIA (Blue)	$ 1.91	$ -	$ 382.00	Oct.11.2015	Hill lay down, row 22
530	25	0	Tech 90	# 14	2	600 V	Tech 90	$ 1.91	$ 47.75	$ -	N/A	Hill lay down, S. side, row 1-2
523	80	0	Tech 90	# 14	2	600 V	Tech 90	$ 1.91	$ 152.80	$ -	N/A	Hill lay down, S. side, row 1
	0	20	Tech 90	# 14	2	600 V	Tech 90	$ 1.91	$ -	$ 38.20	Oct.13.2015	Hill lay down, row 7
550	0	50	Tech 90	# 14	2	600 V	Tech 90	$ 1.91	$ -	$ 95.50	Oct.12.2015	Hill lay down, row 9
285	28	28	Tech 90	# 14	2	600 V	Tech 90	$ 1.91	$ 53.48	$ 53.48	Oct.11.2015	Hill lay down, row 22
???	0	135	Tech 90	# 14	2	1 KV	Tech 90	$ 1.91	$ -	$ 257.85	Oct.10.2015	Hill lay down, row 23
345	120	120	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 264.00	$ 264.00	Oct.12.2015	Hill lay down, row 8
242	240	50	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 528.00	$ 110.00	Oct.12.2015	Hill lay down, row 8
275	0	100	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ -	$ 220.00	Oct.12.2015	Hill lay down, row 8
207	0	25	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ -	$ 55.00	Oct.12.2015	Hill lay down, row 8
420	320	40	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 704.00	$ 88.00	Oct.17.2015	Hill lay down, row 14
452	300	250	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 660.00	$ 550.00	Oct.12.2015	Hill lay down, row 7
203	170	125	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 374.00	$ 275.00	Oct.12.2015	Hill lay down, row 8
94	100	100	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 220.00	$ 220.00	Oct.12.2015	Hill lay down, row 8
492	10	0	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ 22.00	$ -	N/A	Hill lay down, S. side, row 3-4
396	0	40	Tech 90	# 14	3	600 V	Tech 90	$ 2.20	$ -	$ 88.00	Oct.10.2015	Hill lay down, row 22
233	35	20	Tech 90	# 14	4	600 V	Tech 90	$ 2.69	$ 94.15	$ 53.80	Oct.12.2015	Hill lay down, row 8
298	0	60	Tech 90	# 14	4	600 V	Tech 90	$ 2.69	$ -	$ 161.40	Oct.12.2015	Hill lay down, row 8
363	30	10	Tech 90	# 14	4	600 V	Tech 90	$ 2.69	$ 80.70	$ 26.90	Oct.13.2015	Hill lay down, row 8
720	75	75	Tech 90	# 14	4	600 V	Tech 90	$ 2.69	$ 201.75	$ 201.75	Oct.12.2015	Hill lay down, row 8
443	30	30	Tech 90	# 14	4	600 V	Tech 90	$ 2.69	$ 80.70	$ 80.70	Oct.13.2015	Hill lay down, row 8
254	585	317	Tech 90	# 14	5	600 V	Tech 90	$ 3.44	$ 2,012.40	$ 1,090.48	Oct.11.2015	Hill lay down, row 21
168	90	60	Tech 90	# 14	5	600 V	Tech 90	$ 3.44	$ 309.60	$ 206.40	Oct.11.2015	Hill lay down, row 22
412	105	105	Tech 90	# 14	5	600 V	Tech 90	$ 3.44	$ 361.20	$ 361.20	Oct.12.2015	Hill lay down, row 8
457	65	50	Tech 90	# 14	5	600 V	Tech 90	$ 3.44	$ 223.60	$ 172.00	Oct.12.2015	Hill lay down, row 9
448	40	0.00	Tech 90	# 14	5	600 V	Tech 90	$ 3.44	$ 137.60	$ -	N/A	Hill lay down, S. side, row 3-4
262	150	150	Tech 90	# 14	5	600 V	Tech 90	$ 3.44	$ 516.00	$ 516.00	Oct.11.2015	Hill lay down, row 22
301	75	75	Tech 90	# 14	5	600 V	Tech 90	$ 3.45	$ 258.75	$ 258.75	Oct.10.2015	Hill lay down, row 23
397	0	20	Tech 90	# 14	5	600 V	Tech 90	$ 3.45	$ -	$ 69.00	Oct.11.2015	Hill lay down, row 22
243	65	65	Tech 90	# 14	6	600 V	Tech 90	$ 3.79	$ 246.35	$ 246.35	Oct.12.2015	Hill lay down, row 9
385	150	150	Tech 90	# 14	7	600 V	Tech 90	$ 4.20	$ 630.00	$ 630.00	Oct.11.2015	Hill lay down, row 22
191	30	30	Tech 90	# 14	7	600 V	Tech 90	$ 4.20	$ 126.00	$ 126.00	Oct.11.2015	Hill lay down, row 22
109	168	110	Tech 90	# 14	7	600 V	Tech 90	$ 4.20	$ 705.60	$ 462.00	Oct.11.2015	Hill lay down, row 22
323	55	55	Tech 90	# 14	7	600 V	Tech 90	$ 4.20	$ 231.00	$ 231.00	Oct.11.2015	Hill lay down, row 22
220	107	97	Tech 90	# 14	7	600 V	Tech 90	$ 4.20	$ 449.40	$ 407.40	Oct.11.2015	Hill lay down, row 22

Dany Julien (2019)

APPENDIX F2

E&I SHACK

E&I SHACK

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for the results of the Action Research contain two (2) pages under the code 1.2. E&I Shack.

Table F2. 1
E&I Shack

E&I Shack	Contractor Qty	CMT Qty	Part #	Type or Size	Description	Date Counted	Shelf #
E&I Shack	0	10	LTEU2WH20-N		Self Lumenous Exit Light, LTEU2WH20-N	Oct.29.2015	1
E&I Shack	0	6	EX162RW-10-AF-N		Self Lumenous Exit Light, EX162RW-10-AF-N	Oct.29.2015	1
E&I Shack	0	175	H125-TB	1-1/4"	T&B, Conduit Water Tight Hub, 1-1/4", H125-TB	Oct.29.2015	2
E&I Shack	0	40	STX050-462		T&B, Explosion Proof Teck Connector, STX050-462	Oct.29.2015	3
E&I Shack	0	40	STX075-465		T&B, Explosion Proof Teck Connector, STX075-465	Oct.29.2015	3
E&I Shack	0	100	STX075-466		T&B, Explosion Proof Teck Connector, STX075-466	Oct.29.2015	3
E&I Shack	0	60	STX050-464		T&B, Explosion Proof Teck Connector, STX050-464	Oct.29.2015	4
E&I Shack	0	60	STX075-465		T&B, Explosion Proof Teck Connector, STX075-465	Oct.29.2015	4
E&I Shack	0	60	STX075-466		T&B, Explosion Proof Teck Connector, STX075-466	Oct.29.2015	4
E&I Shack	0	8	STX150-470		T&B, Explosion Proof Teck Connector, STX150-470	Oct.29.2015	5
E&I Shack	0	32	STX075-466		T&B, Explosion Proof Teck Connector, STX075-466	Oct.29.2015	5
E&I Shack	0	6	STX250-476		T&B, Explosion Proof Teck Connector, STX250-476	Oct.29.2015	5
E&I Shack	0	4	4HD362W	60A, 600V	Eaton, Heavy Duty Switch, Series C, 60A, 600V, 3 Pole, Fusible, Type 4 & 4X, 4HD362W	Oct.29.2015	6
E&I Shack	0	5			Adhesive M1 (Tube)	Oct.29.2015	6
E&I Shack	0	1	GR305		Crouse Hinds, Refractor, GR305	Oct.29.2015	7
E&I Shack	0	240	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	8
E&I Shack	0	240	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	9
E&I Shack	0	240	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	10
E&I Shack	0	240	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	11
E&I Shack	0	240	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	12
E&I Shack	0	120	STE075		T&B, Extreme Teck Connector, STE075	Oct.29.2015	13
E&I Shack	0	45	STE075		T&B, Extreme Teck Connector, STE075	Oct.29.2015	14
E&I Shack	0	20	TMC2-050A099		CMP Products, Teck Connector, TMC2-050A099	Oct.29.2015	15
E&I Shack	0	60	STX075-466		T&B, Explosion Proof Teck Connector, STX075-466	Oct.29.2015	16
E&I Shack	0	70	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	17
E&I Shack	0	240	STE050		T&B, Extreme Teck Connector, STE050	Oct.29.2015	18
E&I Shack	0	120	STE075		T&B, Extreme Teck Connector, STE075	Oct.29.2015	19
E&I Shack		120	STE075		T&B, Extreme Teck Connector, STE075	Oct.29.2015	20
E&I Shack	0	120	STE075		T&B, Extreme Teck Connector, STE075	Oct.29.2015	21

Dany Julien (2019)

APPENDIX F3

E&I SEA CAN 1

E&I SEA CAN 1

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain eight (8) pages under the code 1.3.1 - E&I Sea Can 1.

Table F3. 1
E&I Sea Can 1

Part #	Contractor QTY	CMT QTY	Type or Size	Description	Date Counted	Sea Can #	Shelf #
WP26V	0	28		Hubbell, +E2:E293Weatherproof Coverfor GFIC Receptacles vertical mounting wet locations with Cover closed	Oct.14.2015	1	1
N7899-W	0	6		Leviton, Smartlock Pro Slim GFIC Outlet with Wall Plate	Oct.14.2015	1	1
SS1	0	9		Pass & Seymour Legrand, smooth 302/304SS MetalWall Plate, 1 Gang Toggle	Oct.14.2015	1	1
BC8376	0	7		T&B, 4" Square Cover for GFIC Receptacle, crushed Corners, 1/2" high	Oct.14.2015	1	1
HBL1221I	0	2		Hubbell, Switch Ivory, single Pole Nylon Toggle, spec. grade, back & side Wire, 20A, 120-277VAC	Oct.14.2015	1	1
5691-2W	0	2		Leviton, Decra Plus Switch, single Pole grounding, white	Oct.14.2015	1	1
1101-CW	0	1		Leviton Industrial, single Pole Toggle Switch, side Wired	Oct.14.2015	1	1
SAK 4/EN	0	800		Weidmueller, Terminal Block	Oct.14.2015	1	2
	0	5		Weidmueller, Terminal Block Jumpers, full Strips	Oct.14.2015	1	2
WDU6	0	120		Weidmueller, Terminal Block	Oct.14.2015	1	2
WDU35/ZA	0	40		Weidmueller, Terminal Block	Oct.14.2015	1	2
WEW35/1	0	25		Weidmueller, End Stop for Terminal Block	Oct.14.2015	1	2
	0	8		Weidmueller, blank end Plate for WDU35/ZA, WAP16+35 & WTW2.5-10	Oct.14.2015	1	2
EW35	0	100		Weidmueller, End Stop	Oct.14.2015	1	2
AP SAK4-10	0	130		Weidmueller, End Block Plate,	Oct.14.2015	1	2
SAK6/en	0	12		Weidmueller, Terminal Block,	Oct.14.2015	1	2
WSI6	0	36		Weidmueller, Terminal Block Disconnector	Oct.14.2015	1	2
D-UK4/10	0	90		Phoenix Contract, Blank End Plate,	Oct.14.2015	1	2
E/NS35N	0	15		Phoenix Contract, End Stop	Oct.14.2015	1	2
	0	10		Weidmueller, Terminal Block ID Holder, SchT 5S >PA< SchT	Oct.14.2015	1	2
	0	20		Weidmueller, Terminal Block ID Holder, SchT 5 >PA 66<	Oct.14.2015	1	2
	0	200	6/32" X 1/2"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	500	6/32" X 1"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	1300	6/32" X 1-1/4"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	1200	6/32" X 1-1/2"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	100	6/32" X 2"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	200	8/32" X 1/2"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	500	8/32" X 1"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	1500	8/32" X 1-1/4"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	1200	8/32" X 1-1/2"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	100	8/32" X 2"	Zinc Plated Machine Screws	Oct.14.2015	1	3
	0	0	10/32" X 1/2"	Zinc Plated Machine Screws	Oct.14.2015	1	3

Dany Julien (2019)

APPENDIX F4

E&I SEA CAN 2

E&I SEA CAN 2

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 1.3.2 - E&I Sea Can 2.

Table F4. 1
E&I Sea Can 2

Part #	Contractor Qty	CMT Qty	Type or Size	Description	Date Counted	Sea Can #	Shelf #
4HD362W	0	2	60A/600V	Eaton, Heavy Duty Safety Switch, 3 Pole Fusible, 60A/600V, Series B, Type 4 & 4X Rated, 4HD362W	Oct.23.2015	2	By Front Door
	0	1		Crane Wiring Parts	Oct.23.2015	2	"
	0	5		Jct. Boxes Labeled Area 376 - EJB-001, EJB-002, EJB-003, EJB-004, EJB-005,	Oct.23.2015	2	"
	0	1		Jct. Boxes Labeled Area 376 - LJB-003	Oct.23.2015	2	"
	0	4		Jct. Boxes Labeled Area 376 - IJB-101, IJB-102, IJB-203, IJB-204	Oct.23.2015	2	"
	0	2		Lighting Contactor Panel, 120VAC as per Drawg. ML376-P-198, in Stock MCL-21234 from GTK Electric Controls	Oct.23.2015	2	"
TC 101A-SSR30A-240-C-P3-2R-DCALH/LCDH	0	2	240V	Thermon, Heat Trace Control & Monitoring Unit, Mod.#: TC 101A-SSR30A-240-C-P3-2R-DCALH/LCDH	Oct.23.2015	2	"
GR305	0	1		Crouse Hinds, Refractor, GR305	Oct.23.2015	2	"
U514-ASS6	0	75		T&B, Beam Clamp, U514-ASS6	Oct.23.2015	2	"
U563 HDG	0	200	3/8"	T&B, Beam Clamp, U563 HDG, for 3/8" Rod	Oct.23.2015	2	"
	0	150	3/8"	Quick Link Chain Joiners, Stainless Steel, 3/8"	Oct.23.2015	2	"
MUV504	0	1		Madison Electric Motors Ultraline-PE,Premium Efficiency invertor Duty Motor, Cat.#: MUV504, Type NEP 145T 1-4, HP: 1.5, Frame: 145T, 575V, 3 PH, Enclosure: TEFC, Max.Amb: 40 Deg.C, 1.7A, 1750 RPM, P.F. 0.78, Nema Design B, 59.5 Lbs, Serial #: 33040376	Oct.23.2015	2	"
	0	100		Conrner Angle Vertical, 2 Hole, Stainless Steel	Oct.23.2015	2	1
	0	100	1/4"	Spring Nut, Stainless Steel, 1/4"	Oct.23.2015	2	2
	0	150	3/8"	Spring Nut, Stainless Steel, 3/8"	Oct.23.2015	2	3
	0	75	1/2"	Spring Nut, Stainless Steel, 1/2"	Oct.23.2015	2	4
	0	75		Conrner Angle Vertical, 3 Hole, Stainless Steel	Oct.23.2015	2	5
	0	1500	1/4"	Hex Nut, Stainless Steel, 1/4"	Oct.23.2015	2	6
	0	300	1/4"	Lock Washer, Stainless Steel, 1/4"	Oct.23.2015	2	7
	0	1000	1/4"	Flat Washer, Stainless Steel, 1/4"	Oct.23.2015	2	8
	0	16		Conrner Angle Vertical, 4 Hole, Stainless Steel	Oct.23.2015	2	9
	0	1500	3/8"	Hex Nut, Stainless Steel, 3/8"	Oct.23.2015	2	10
	0	3000	3/8"	Lock Washer, Stainless Steel, 3/8"	Oct.23.2015	2	11
	0	15	3/8"	Flat Washer, Stainless Steel, 3/8"	Oct.23.2015	2	12
	0	300	1/2"	Coupling Nut, Stainless Steel, 1/2"	Oct.23.2015	2	13
	0	100	1/2"	Hex Nut, Stainless Steel, 1/2"	Oct.23.2015	2	14
	0	1500	1/2"	Lock Washer, Stainless Steel, 1/2"	Oct.23.2015	2	15
	0	2000	1/2"	Flat Washer, Stainless Steel, 1/2"	Oct.23.2015	2	16
	0	120		Open Angle Strut Fitting 45 Deg., Stainless Steel, 2 Hole	Oct.23.2015	2	17
	0	100		Closed Angle Strut Fitting 45 Deg., Stainless Steel, 2 Hole	Oct.23.2015	2	18
	0	1		Corner Plate Strut Fitting "L", 3 Hole	Oct.23.2015	2	19
	0	30		Flat Splice plate Strut Fitting, 4 Hole	Oct.23.2015	2	20
	0	100		Open Angle Strut Fitting 45 Deg., Stainless Steel, 4 Hole	Oct.23.2015	2	21
	0	50		Closed Angle Strut Fitting 45 Deg., Stainless Steel, 4 Hole	Oct.23.2015	2	22
	0	120		Flat "L" Strut Fitting, Stainless Steel, 4 Hole	Oct.23.2015	2	23
B422-1SS4	0	12		B-Line, Pipe Clamp Stainless Steel, 14136A, B422-1SS4	Oct.23.2015	2	24
	0	50		Open Angle Strut Fitting 45 Deg., Stainless Steel, 4 Hole, CB781-45-X6	Oct.23.2015	2	25

Dany Julien (2019)

APPENDIX F5

E&I LAYDOWN

E&I LAYDOWN

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 1.4 - E&I Laydowns.

Table F5. 1
E&I Laydown

Contractor QTY	CMT Qty	Description	Date Counted	LOCATION
150	118	Stainless Double Strut 10 ft	Oct.07.2015	Hill lay-down-Row 5
2	0	Stainless Double Strut 20 ft	Oct.07.2015	Hill lay-down
45	59	Stainless Shallow Strut 10 ft	Oct.07.2015	Hill lay-down-Row 3 & 5
30	0	Stainless 1"5/8 Strut 10 ft	Oct.07.2015	Hill lay-down-Row 5
110	124	Galvanized Double Strut 10 ft	Oct.07.2015	Hill lay-down-Row 3 & 5
20	11	Galvanized Double Strut Shallow 10 ft	Oct.07.2015	Hill lay-down-Row 3 & 5
110	207	Galvanized Strut Shallow 10 ft	Oct.07.2015	Hill lay-down-Row 3
50	52	Galvanized 1" 5/8 Strut 10 ft	Oct.07.2015	Hill lay-down-Row 3
70	53	Galvanized 1" 5/8 Strut perforated 20 ft	Oct.07.2015	Hill lay-down-Row 2
17	26	Stainless wall bracket 12"	Oct.07.2015	Hill lay-down-Row 4
0	6	Stainless wall bracket 24"	Oct.07.2015	Hill lay-down-Row 4
8	6	Stainless wall bracket 30"	Oct.07.2015	Hill lay-down-Row 4
80	75	Ready Rod 1/2" Stainless 10ft	Oct.09.2015	Hill lay-down-Row 4
20	16	Ready Rod 3/8" Stainless 10ft	Oct.09.2015	Hill lay-down-Row 4
150	208	Ready Rod 1/2" galvanized 10 ft	Oct.09.2015	Hill lay-down-Row 4 & 5
30	21	Ready Rod 3/8" galvanized 10 ft	Oct.09.2015	Hill lay-down-Row 4
20	39	Ready Rod 1/4" galvanized 10 ft	Oct.09.2015	Hill lay-down-Row 4
4	4	Peaked tray cover 18" Stainless 10 ft	Oct.08.2015	Hill lay-down-Row 10 & 11
3	3	Peaked tray cover 12" Stainless 10 ft	Oct.08.2015	Hill lay-down-Row 10 & 11
20	84	Tray barrier Stainless 6" 10 ft	Oct.08.2015	Hill lay-down-Row 3 & 10
60	77	Tray barrier Stainless 6" 5 ft	Oct.08.2015	Hill lay-down-Row 5
20	2	Peaked tray cover 18" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
5	0	Peaked tray cover 12" Galvanized 5 ft	Oct.08.2015	Hill lay-down
70	0	Peaked tray cover 6" Galvanized 5 ft	Oct.08.2015	Hill lay-down
0	11	Tray cover 18" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
92	92	Tray cover 12" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
80	95	Tray cover 6" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
50	40	Tray cover 4" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
80	100	Tray Barrier 6" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
0	62	Tray Barrier 6" Galvanized 6 ft	Oct.08.2015	Hill lay-down-Row 4
20	3	Tray Barrier 4" Galvanized 5 ft	Oct.08.2015	Hill lay-down-Row 4
10	9	Metal Strut cover 10 ft	Oct.07.2015	Hill lay-down-Row 4

Dany Julien (2019)

APPENDIX F6

E&I NORSEMAN

E&I NORSEMAN

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain five (5) pages under the code 1.5 – E&I Norseman.

Table F6. 1
E&I Norseman

Tag / Style Number	Contractor Qty	CMT Qty	Size	Part Number	Description	Date Counted	Building	Location	Area
	54	54		KGU2	Globe Guard	Nov.09.2015	Norseman	G3/G7	376
	29	29		KPB175HMT	Ballast Body 175W MH	Nov.09.2015	Norseman	G3/G7	376
	12	12		H1610C KR2-AN	Reflector White 30 Degree	Nov.09.2015	Norseman	G3/G7	376
	20	20		M400/U	Light Bulb 400w MB Metal Halide	Nov.09.2015	Norseman	D4	376
	47	47		M175/U	Light Bulb 175w MB Metal Halide	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	3	3		KR2-ST	White Reflector Shade	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	1	1		KR2-AN	Reflector White 30 Degree	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	9	9		KPB250HMT	Ballast Body 250W MH	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	67	67		KPWB-100	Wall Mounting Hood / 1" Hub	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	20	20		H1610C KR2-AN	Reflector White 30 Degree	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	20	20		VPGL-2HR	Globe Clear Glass	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	6	0		MX874	Fiber Cable		Norseman	E6	376
	20	20		KPWB-100	Wall Mounting Hood / 1" Hub	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	16	16		KPB100HMT	Lighting Fixture	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	4	4		KPB100LMT	Ballast Body	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	51	51		VPGL-2HR	Globe Clear Glass	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	13	13		KPB250HMT	Ballast Body 250W MH	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	12	12		KR2-ST	Reflector White Shade	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	1	1		KPC100	Pendant Mounting Hood	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	3	3		KPA100	Rigid Pendant Mounting Hood	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
620252	1	1			Cabinet Nema 12 c/w Fan and Ready for a SSG3KRM UPS 51"H x 24"W x 31.5"D	Nov.09.2015	Norseman	14	376
73032	3	0	6"		Flange FRP Blind	Nov.09.2015	Norseman	C12	335
73032	3	0	4"		Flange FRP Blind	Nov.09.2015	Norseman	C12	335
73032	3	0	3"		Flange FRP Blind	Nov.09.2015	Norseman	C12	335
73032	3	0	3"		Gasket Teflon	Nov.09.2015	Norseman	C12	335
73032	1	0	4"		Gasket XH 300 Teflon	Nov.09.2015	Norseman	C12	335
73032	2	0	24"		Gasket Teflon	Nov.09.2015	Norseman	C12	335
73032	1	0			Roll Perma-Pipe Heat Shrink	Nov.09.2015	Norseman	C12	335
	26	0	2"		Flange RFSW 300lb A105	Nov.09.2015	Norseman	C3	335
	17	0	2 1/2"		Flange FF Vanstone 150lb A105	Nov.09.2015	Norseman	C3	335
	64	0	2"		Flange Vanstone 150lb A105	Nov.09.2015	Norseman	C3	335
	44	0	2"		Flange BLRF 150lb A105	Nov.09.2015	Norseman	C3	335

Dany Julien (2019)

APPENDIX F7

PIPE FITTINGS NORSEMAN

PIPE FITTINGS NORSEMAN

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 1.6 – PF Norseman.

Table F7. 1
Pipe Fittings Norseman

Tag / Style Number	Contractor Qty	CMT Qty	Size	Part Number	Description	Date Counted	Building	Location	Area
	54	54		KGU2	Globe Guard	Nov.09.2015	Norseman	G3/G7	376
	29	29		KPB175HMT	Ballast Body 175W MH	Nov.09.2015	Norseman	G3/G7	376
	12	12		H1610C KR2-AN	Reflector White 30 Degree	Nov.09.2015	Norseman	G3/G7	376
	20	20		M400/U	Light Bulb 400w MB Metal Halide	Nov.09.2015	Norseman	D4	376
	47	47		M175/U	Light Bulb 175w MB Metal Halide	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	3	3		KR2-ST	White Reflector Shade	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	1	1		KR2-AN	Reflector White 30 Degree	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	9	9		KPB250HMT	Ballast Body 250W MH	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	67	67		KPWB-100	Wall Mounting Hood / 1" Hub	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	20	20		H1610C KR2-AN	Reflector White 30 Degree	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	20	20		VPGL-2HR	Globe Clear Glass	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	6	0		MX874	Fiber Cable	Nov.09.2015	Norseman	E6	376
	20	20		KPWB-100	Wall Mounting Hood / 1" Hub	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	16	16		KPB100HMT	Lighting Fixture	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	4	4		KPB100LMT	Ballast Body	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	51	51		VPGL-2HR	Globe Clear Glass	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	13	13		KPB250HMT	Ballast Body 250W MH	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	12	12		KR2-ST	Reflector White Shade	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	1	1		KPC100	Pendant Mounting Hood	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
	3	3		KPA100	Rigid Pendant Mounting Hood	Nov.09.2015	Norseman	G3/G7/F6/F12/G4/G8	376
620252	1	1			Cabinet Nema 12 c/w Fan and Ready for a SSG3KRM UPS 51"H x 24"W x 31.5"D	Nov.09.2015	Norseman	14	376
73032	3	0	6"		Flange FRP Blind	Nov.09.2015	Norseman	C12	335
73032	3	0	4"		Flange FRP Blind	Nov.09.2015	Norseman	C12	335
73032	3	0	3"		Flange FRP Blind	Nov.09.2015	Norseman	C12	335
73032	3	0	3"		Gasket Teflon	Nov.09.2015	Norseman	C12	335
73032	1	0	4"		Gasket XH 300 Teflon		Norseman	C12	335
73032	2	0	24"		Gasket Teflon		Norseman	C12	335
73032	1	0			Roll Perma-Pipe Heat Shrink		Norseman	C12	335
	26	0	2"		Flange RFSW 300lb A105		Norseman	C3	
	17	0	2 1/2"		Flange FF Vanstone 150lb A105		Norseman	C3	
	64	0	2"		Flange Vanstone 150lb A105		Norseman	C3	
	44	0	2"		Flange BLRF 150lb A105		Norseman	C3	

Dany Julien (2019)

APPENDIX F8

Cu PIPE FITTINGS

Cu PIPE FITTINGS

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain two (2) pages under the code 2.1 – Cu Pipe Fittings.

Table F8. 1
Cu Pipe Fittings

Category	Contractor Qty	CMT Qty	Size (In)	Description	Spec	Sch/Rat	Date Counted	Location
BRASS CAP		1	2.00	BRASS CAP	N/A	N/A	OCT 17 2015	S1
BRASS CAP		10	1.00	BRASS CAP	N/A	N/A	OCT 17 2015	S1
BRASS CAP		9	0.75	BRASS CAP	N/A	N/A	OCT 17 2015	S1
BRASS COUPLING		1	2 X 1	BRASS REDUCING COUPLING	N/A	N/A	OCT 17 2015	S1
BRASS COUPLING		1	1.5 X 1	BRASS REDUCING COUPLING	N/A	N/A	OCT 17 2015	S1
BRASS COUPLING		8	0.75	BRASS COUPLING	N/A	N/A	OCT 17 2015	S1
BRASS ELBOW		4	2.00	BRASS 90 ELBOW	N/A	N/A	OCT 17 2015	S1
BRASS ELBOW		1	1.50	BRASS 90 ELBOW	N/A	N/A	OCT 17 2015	S1
BRASS ELBOW		28	1.00	BRASS 90 ELBOW	N/A	N/A	OCT 17 2015	S1
BRASS ELBOW		25	0.75	BRASS 45 ELBOW	N/A	N/A	OCT 17 2015	S1
BRASS ELBOW		1	0.75	BRASS 90 ELBOW	N/A	N/A	OCT 17 2015	S1
BRASS FLANGE		2	2.00	BRASS FLANGE 150#	N/A	N/A	OCT 17 2015	S1
BRASS FLANGE		4	3.00	BRASS FLANGE 150#	N/A	N/A	OCT 17 2015	S1
BRASS TEE		3	2 X 2 X 1	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		1	2 X 2 X 1.5	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		2	2 X 2 X 2	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		3	1 X 1 X 0.75	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		2	0.75 X 0.75 X 0.5	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		2	0.75 X 0.5 X 0.5	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		1	1 X 0.75 X 0.5	BRASS TEE	N/A	N/A	OCT 17 2015	S1
BRASS TEE		14	0.75 X 0.75 X 0.75	BRASS TEE	N/A	N/A	OCT 17 2015	S1
CAMLOCK		6	2.00	MNPT X HOSE BARB, CS	N/A	N/A	OCT 17 2015	S1
CAMLOCK		4	2.00	MALE PLUG CAMLOCK (ALUMINUM)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		3	2.00	DUST CAP CAMLOCK (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		2	2.00	MNPT X MALE CAMLOCK (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		1	2.00	FNPT X MALE CAMLOCK (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		2	0.75	FNPT X MALE CAMLOCK (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		2	0.75	MNPT X MALE CAMLOCK (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		4	1.50	DUST CAP CAMLOCK (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		4	1.50	FEMALE CAMLOCK X HOSE BARB (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		1	1.50	MALE CAMLOCK X HOSE BARB (316SS)	N/A	N/A	OCT 17 2015	S1
CAMLOCK		2	2.00	FEMALE CAMLOCK X HOSE BARB (316SS)	N/A	N/A	OCT 17 2015	S1
CHICAGO		10	1.00	MNPT X CHICAGO (316SS)	N/A	N/A	OCT 17 2015	S1
COPPER ADAPTER	3	3	0.75	COPPER X MIP ADAPTER	P30	TYPE L	OCT 17 2015	S1 A40
COPPER ADAPTER	3	3	0.75	COPPER X FIP ADAPTER	P30	TYPE L	OCT 17 2015	S1 A40
COPPER ADAPTER	1	1	1.00	COPPER X FIP ADAPTER	P30	TYPE L	OCT 17 2015	S1 A40

Dany Julien (2019)

APPENDIX F9

CS BARE FITTINGS

CS BARE FITTINGS

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 2.2.1 – Carbon Steel Bare Fittings.

Table F9. 1
CS Bare Fittings

Category	Contractor Qty	CMT Qty	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
CS BLIND	3	4	0.750	Ea	RF BLIND FLANGE, A105	P21	300	Oct 14 2015	S1 B11
CS BLIND	0	20	0.500	Ea	RF BLIND FLANGE, A105	P21	150	OCT 25 2015	WH C9
CS BLIND	34	32	0.750	Ea	RF BLIND FLANGE, A105	P20	150	Oct 14 2015	S1 B11
CS BLIND	8	0	0.750	Ea	RF BLIND FLANGE, A105	P20	300	Oct 14 2015	S1 B11
CS BLIND	0	3	1.000	Ea	RF BLIND FLANGE, A105	P20	300	Oct 14 2015	S1 B11
CS BLIND	11	13	1.000	Ea	RF BLIND FLANGE, A105	P20	150	Oct 14 2015	S1 B11
CS BLIND	2	0	1.500	Ea	RF BLIND FLANGE, A105	P20	150	NOV 07 2015	
CS BLIND	2	0	1.500	Ea	RF BLIND FLANGE, A105	P20	150	NOV 07 2015	
CS BLIND	2	2	2.000	Ea	FF BLIND FLANGE, A105	P20	150	Oct !5 2015	S1 A57
CS BLIND	0	6	2.000	Ea	RF BLIND FLANGE, A105	P20	300	Oct !5 2015	S1 A42 / WH C9,
CS BLIND	9	52	2.000	Ea	RF BLIND FLANGE, A105	P20	150	Oct !5 2015	S1 A42 / WH C9/C3
CS BLIND	3	3	3.000	Ea	RF BLIND FLANGE, A105	P20	150	Oct !5 2015	S1 A42 / WH C4
CS BLIND	8	6	3.000	Ea	RF BLIND FLANGE, A105	P21	300	Oct !5 2015	S1 A42
CS BLIND	0	1	3.000	Ea	FF BLIND FLANGE, A105	P20	150	Oct 15 2015	S1 A58
CS BLIND	0	2	4.000	Ea	RF BLIND FLANGE, A105 Tapped to 2 " NPT on c	P20	150	Oct 15 2015	S1 A41
CS BLIND	11	0	4.000	Ea	RF BLIND FLANGE, A105	P20	150	NOV 07 2015	
CS BLIND	2	2	4.000	Ea	RF BLIND FLANGE, A105	P21	300	Oct 15 2015	S1 A42
CS BLIND	1	0	4.000	Ea	RF BLIND FLANGE (C/W 0.75" NPT ON BOTTO	P20	150	NOV 07 2015	
CS BLIND	2	0	6.000	Ea	RF BLIND FLANGE (C/W 1.5" NPT ON CENTER	P20	150	NOV 07 2015	
CS BLIND	1	1	6.000	Ea	RF BLIND FLANGE, A105	P21	300	Oct 15 2015	S1 A57
CS BLIND	2	2	6.000	Ea	RF BLIND FLANGE, A105	P20	150	Oct 15 2015	S1 B42
CS BLIND	9	14	8.000	Ea	RF BLIND FLANGE, A105	P20	150	Oct 15 2015	S1 A58 WH C9
CS BLIND	0	3	8.000	Ea	RF BLIND FLANGE, A105 TAPED TO 3 "FNPT	P20	150	OCT 25 2015	WH C9
CS BUSHING	16	21	0.75 X 0.25	Ea	THD BUSHING, A105	P20	3M	OCT 05 2015	S1 A13
CS BUSHING	5	4	0.75 X 0.375	Ea	THD BUSHING, A105	P20	3M	OCT 14 2015	S1 A13
CS BUSHING	2	2	1 X 0.5	Ea	THD BUSHING, A105	P20	3M	OCT 05 2015	S1 A13
CS CAP	2	0	0.500	Ea	THD CAP, A105	N/A	150#	NOV 07 2015	
CS CAP	12	12	0.500	Ea	THD CAP, A105	P20	3M	Oct 14 2015	S1 B10
CS CAP	37	37	0.750	Ea	THD CAP, A105	P20	3M	Oct 14 2015	S1 B10
CS CAP	0	1	1.000	Ea	SW CAP, A105	P20	3M	Oct 14 2015	S1 B8
CS CAP	3	3	1.500	Ea	SW CAP, A105	P20	3M	Oct 14 2015	S1 B10
CS CAP	0	1	2.000	Ea	SW CAP, A105	P20	3M	Oct 14 2015	S1 B8
CS CAP	10	10	1.500	Ea	THD CAP, A105	P20	3M	Oct 14 2015	S1 B10
CS CAP	28	28	2.000	Ea	BW CAP, A105	P20	SCH40	Oct 14 2015	S1 B41
CS COUPLING	1	0	0.500	Ea	THD COUPLING, A105	P20	3M	NOV 08 2015	
CS COUPLING	2	5	0.750	Ea	THD COUPLING, A105	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	11	11	0.750	Ea	SW COUPLING, A234	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	15	14	1.000	Ea	THD COUPLING, A105	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	1	1	1.000	Ea	SW X THD COUPLING, A350 LF2	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	8	8	1.000	Ea	SW COUPLING, A105	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	1	1	1.250	Ea	SW COUPLING, A234	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	14	12	1.500	Ea	THD COUPLING, A105	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	5	3	1.500	Ea	SW COUPLING, A105	P20	3M	Oct 14 2015	S1 B8
CS COUPLING	3	3	2.000	Ea	THD COUPLING, A105	P20	3M	Oct 14 2015	S1 B8

Dany Julien (2019)

APPENDIX F10

CS GALVANISED FITTINGS

CS GALVANISED FITTINGS

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain two (2) pages under the code 2.2.2 – Carbon Steel Galvanised Fittings.

Table F10. 1
CS Galvanised Fittings

Category	Contractor Qty	CMT Qty	Length	Size (In)	Description	Spec	Sch/Rat	Date Counted	Location
EP CAP	0	3		0.50	CAP, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP CAP	0	4		1.00	CAP, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A5
EP CAP	0	2		2.00	CAP, CS A105, SW, B16.11, (EP)	P20	3000LB	OCT 16 2015	S1 A39
EP CAP	3	0		0.50	CAP, CS A105, SW, B16.11, (EP)	P20	3000LB	NOV 08 2015	S1
EP Blind	0	3		1.50	RF Blind FLANGE A105, B16.11 (EP)	p20	150	OCT 16 2015	S1 A4
EP COUPLING	0	54		0.75	FULL COUPLING, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP COUPLING	0	10	1.50	.75 X.5	REDUCING COUPLING, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 21 2015	S1 A6
EP COUPLING	54	0		0.75	REDUCING COUPLING, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 08 2015	S1
EP COUPLING	9	9		1.50	FULL COUPLING, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A6
EP COUPLING	48	48		2.00	FULL COUPLING, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A6
EP ELBOW	0	6		0.75	ELBOW 90 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP ELBOW	6	0		0.75	ELBOW 90 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 08 2015	S1
EP ELBOW	14	14		1.00	ELBOW 90 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 B11
EP ELBOW	0	1		1.50	ELBOW 90 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP ELBOW	0	4		2.00	ELBOW 45 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP ELBOW	0	2		2.00	ELBOW 45 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP ELBOW	1	0		1.50	ELBOW 90 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 08 2015	S1
EP ELBOW	6	0		2.00	ELBOW 45 DEG, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 08 2015	S1
EP NIPPLE	1	2	3.00	1.00	NIPPLE, TOE, B36.10, 76mm LG, (EP)	P20	S80	OCT 16 2015	S1 A5
EP NIPPLE	3	2	4.00	1.00	NIPPLE, TBE, B36.10, 100mm LG, (EP)	P20	S80	OCT 16 2015	S1 A19
EP NIPPLE	0	2	4.00	1.00	NIPPLE, TOE, B36.10, 100mm LG, (EP)	P20	S80	OCT 16 2015	S1 A5
EP NIPPLE	0	2	3.00	1.50	NIPPLE, PBE, B36.10, 76mm LG, (EP)	P20	S80	OCT 16 2015	S1 A5
EP NIPPLE	3	9	3.00	1.50	NIPPLE, TOE, B36.10, 76mm LG, (EP)	P20	S80	OCT 16 2015	S1 A5
EP PLUG	0	1		0.75	PLUG HEX, CS A105, MNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP PLUG	0	3		1.00	PLUG HEX, CS A105, MNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP SWAGE	0	1		2X1	SWAGE PBE CS A105 SCH 80	P20	SCH 80	OCT 16 2015	S1 A5
EP TEE	13	31		0.75	TEE, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A21
EP TEE	10	14		1.00	TEE, CS A105, FNPT, B16.11, (EP)	P20	3000 LB	OCT 15 2015	S1 A21 /A39
EP TEE	5	4		2.00	TEE, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A22
EP UNION	0	8		0.50	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP UNION	0	2		0.75	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 09 2015	S1
EP UNION	8	8		0.50	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A20
EP UNION	2	0		0.75	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	NOV 08 2015	S1
EP UNION	8	8		1.00	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OcT 16 2015	S1 A20
EP UNION	1	11		1.50	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OcT 16 2015	S1 A20
EP UNION	13	32		2.00	UNION, CS A105, FNPT, B16.11, (EP)	P20	3000LB	OCT 15 2015	S1 A23
HDG BLIND	2	2		1.50	FLANGE BLIND, CS A105, RF, B16.5, (HDG)	P20	150LB	OCT 15 2015	S1 A23
HDG CAP	2	2		0.50	CAP, CS A105, FNPT, B16.11, (HDG)	P20	3000LB	OCT 15 2015	S1 A39
HDG CAP	0	8		0.75	CAP, CS A105, FNPT, B16.11, (HDG)	P20	3000LB	NOV 09 2015	S1
HDG CAP	2	0		1.50	CAP, CS A105, FNPT, B16.11, (HDG)	P20	3000LB	NOV 08 2015	S1
HDG CAP	10	10		2.00	CAP, CS A105, FNPT, B16.11, (HDG)	NA	150LB	OcT 16 2015	S1 B11
HDG COUPLING	52	52		0.75	FULL COUPLING, CS A105, FNPT, B16.11, (HDG)	P20	3000LB	OcT 16 2015	S1 A36
HDG COUPLING	0	1		2X1	RED. COUPLING, CS A105, FNPT, B16.11, (HDG)	P20	3000LB	NOV 09 2015	S1
HDG COUPLING	0	1		2X1.25	RED. COUPLING, CS A105, FNPT, B16.11, (HDG)	P20	3000LB	NOV 09 2015	S1

Dany Julien (2019)

APPENDIX F11

CS & Cu PIPING

CS & Cu PIPING

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain two (2) pages under the code 2.2.4 – Carbon Steel & Copper Piping.

Table F11. 1
CS & Cu Piping

Category	Contractor Length	CMT Length	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
TUBE	0	24	0.500	Ft	COPPER WATER TUBE, TYPE-L (O50), SMLS, ASTM B-88-09	P30	Type L	OCT 16 2015	BP PR 10
TUBE	0	36	0.750	Ft	COPPER WATER TUBE, TYPE-L (O50), SMLS, ASTM B-88-09	P30	Type L	OCT 16 2015	BP PR 10
TUBE	0	12	1.000	Ft	COPPER WATER TUBE, TYPE-L (O50), SMLS, ASTM B-88-09	P30	Type L	OCT 16 2015	BP PR 10
TUBE	0	84	1.500	Ft	COPPER WATER TUBE, TYPE-L (O50), SMLS, ASTM B-88-09	P30	Type L	OCT 16 2015	BP PR 10
TUBE	0	120	2.000	Ft	COPPER WATER TUBE, TYPE-L (O50), SMLS, ASTM B-88-09	P30	Type L	OCT 16 2015	BP PR 10
PIPE	0	20	0.500	Ft	A106 YELLOW		SCH80	OCT 16 2015	BP PR 10
PIPE	0	40	0.500	Ft	A106 GREEN		SCH80	OCT 16 2015	BP PR 10
PIPE	0	20	1.000	Ft	A312 304		SCH40	OCT 16 2015	BP PR 10
PIPE	0	20	1.250	Ft	A312 304		SCH40	OCT 16 2015	BP PR 10
PIPE	0	80	0.500	Ft	A53 GREEN	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	20	0.750	Ft	A53 GREEN	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	80	1.000	Ft	A53 GREEN	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	40	1.500	Ft	A53 GREEN	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	100	2.000	Ft	A53 GREEN	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	200	180	0.750	Ft	A53 HDG	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	40	0.500	Ft	A53 HDG	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	160	160	1.000	Ft	A53 HDG	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	40	80	1.500	Ft	A53 HDG	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	200	200	2.000	Ft	A53 HDG	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	240	240	2.000	Ft	A53 HDG	P20	SCH40	OCT 16 2015	BP PR 10
PIPE	0	14	3.000	Ft	ABS PIPE (BLACK)				
PIPE	0	13	4.000	Ft	GT PIPE, ASTM D-2996	P60	150LB	OCT 16 2015	BP PR 10
PIPE	0	14	6.000	Ft	GT PIPE, ASTM D-2996	P60	150LB	OCT 16 2015	BP PR 10
PIPE	0	20	12.000	Ft	GT PIPE, ASTM D-2996	P60	150LB	OCT 16 2015	BP PR 10
PIPE	0	95	1.500	Ft	PIPE, ASTM B862 Ti GR. 2	P80	SCH40	OCT 16 2015	BP PR 10
PIPE	0	20	8.000	Ft	PIPE, CS	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	20	8.000	Ft	PIPE, CS	P20	SCH40	OCT 16 2015	BP PR 10
PIPE	0	20	1.000	Ft	PIPE, CS A53-B, ERW, B36.10 (Painted Blue)	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	20	1.500	Ft	PIPE, CS A53-B, ERW, B36.10 (Painted Blue)	P20	SCH80	OCT 16 2015	BP PR 10
PIPE	0	160	1.500	Ft	PIPE, CS A53-B, ERW, B36.10 (Painted Blue)	P20	SCH80	OCT 16 2015	BP PR 10

Dany Julien (2019)

APPENDIX F12

FRP FITTINGS

FRP FITTINGS

This appendix demonstrates part of the results as only one (1) partial page of data is inserted below. Original documents for these Action Research results contain two (2) pages under the code 2.3.1 –FRP Fittings.

Table F12. 1
FRP Fittings

Category	Contractor Qty	CMT Qty	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
GT COUPLING	3	3	6.00	Ea	COUPLING - SOCKET X SOCKET, GREEN THREAD	P60	GREEN THREAD	OCT 18 2015	S3B30
GT BLIND	0	1	2.00		BLIND FLANGE FF	P60	150	OCT 18 2015	S3 B12
GT BLIND	0	6	2.50		BLIND FLANGE FF	P60	150	OCT 18 2015	S3 B12
GT BLIND	0	1	3.00		BLIND FLANGE FF	P60	150	OCT 18 2015	S3 B12
GT BLIND	0	1	3.00		BLIND FLANGE RF	P60	150	OCT 18 2015	S3 B12
GT BLIND	0	2	6.00		BLIND FLANGE FF	P60	150	OCT 18 2015	S3 B12
GT FLANGE	1	1	4.00	Ea	FLANGE - SJFF, GREEN THREAD, NOV HP16	P60	150	OCT 18 2015	S3 B49
GT FLANGE	0	1	2.00	Ea	FLANGE - FF CL150, BUTT & WRAP STYLE	P60	150	OCT 18 2015	S3 B30
GT FLANGE	0	2	2.50	Ea	FLANGE - FF CL150, BUTT & WRAP STYLE	P60	150	OCT 18 2015	S3 B30
GT FLANGE	40	40	4.00	Ea	FLANGE - FF CL150, BUTT & WRAP STYLE	P60	150	OCT 18 2015	S3 B49/50/13/45
GT FLANGE	7	7	6.00	Ea	FLANGE - SJFF, GREEN THREAD, NOV HP16	P60	150	OCT 18 2015	S3 B49
GT FLANGE	1	4	6.00	Ea	FLANGE - FF CL150, BUTT & WRAP STYLE	P60	150	OCT 18 2015	S3 B30
GT SADDLE	1	0	4 X 1	Ea	SADDLE - C/W THREADED CONNECTION	P60	GREEN THREAD	NOV 08 205	S3 B30
GT SADDLE	0	1	6 X 1	Ea	SADDLE - C/W THREADED CONNECTION	P60	GREEN THREAD	OCT 18 2015	S3 B30
GT SADDLE	1	1	6 X 1.5	Ea	SADDLE - C/W THREADED CONNECTION	P60	GREEN THREAD	OCT 18 2015	S3 B12
GT SADDLE	3	0	6 X 1.5	Ea	SADDLE - C/W THREADED CONNECTION	P60	GREEN THREAD	OCT 18 2015	S3 B12
RB BLIND	0	1	1.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B28
RB BLIND	0	2	1.50	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B28
RB BLIND	4	11	2.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B28
RB BLIND	0	1	3.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B28
RB BLIND	4	4	4.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B28
RB BLIND	0	2	8.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B29
RB BLIND	7	9	6.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B29
RB BLIND	0	3	10.00	Ea	BLIND FLANGE RF	P61	150	OCT 18 2015	S3 B47
RB BUSHING	0	1	2 X .75	Ea	INSERT X FNPT BUSHING	P61	RB 2530	OCT 18 2015	S3 B19
RB BUSHING	0	6	2 X 1	Ea	INSERT BUSHING	P61	RB 2530	OCT 18 2015	S3 B19
RB BUSHING	4	4	2 X 1	Ea	INSERT X FNPT BUSHING	P61	RB 2530	OCT 18 2015	S3 B19
RB BUSHING	19	19	2 X 1.5	Ea	INSERT BUSHING	P61	RB 2530	OCT 18 2015	S3 B19
RB BUSHING	3	3	2 X 1.5	Ea	INSERT X FNPT BUSHING	P61	RB 2530	OCT 18 2015	S3 B19
RB BUSHING	4	4	3 X 2	Ea	BUSHING	P61	RB 2530	OCT 18 2015	S3 B45
RB BUSHING	6	6	6 X 4	Ea	BUSHING	P61	RB 2530	OCT 18 2015	S3 B45
RB BUSHING	5	5	8 X 4	Ea	BUSHING	P61	RB 2530	OCT 18 2015	S3 B45

Dany Julien (2019)

APPENDIX F13

FRP PIPING

FRP PIPING

This appendix demonstrates part of the results as only one (1) page of data is inserted below. Original documents for these Action Research results contain one (1) page under the code 2.3.2 – FRP Piping.

Table F13. 1
FRP Piping

Category	Contractor Length	CMT Length	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
PIPE	0	0	8.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE	P61	150LB	11-Nov-15	BP PR 1
PIPE	0	140	1.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 1
PIPE	0	180	1.50	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 1
PIPE	0	0	2.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 1
PIPE	0	160	2.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 2
PIPE	0	60	3.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 2
PIPE	0	780	3.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 3
PIPE	0	0	4.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 3
PIPE	0	60	4.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 4
PIPE	0	280	6.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 5
PIPE	0	180	8.00	Ft	PIPE, FRP ASTM D2997, RTRP-21CQ-4456, PE, B31.3 (RB-2530)	P61	150LB	17-Oct-15	BP PR 6
Total	0	1,840							
Adjustment	0								
sku	111								

Dany Julien (2019)

APPENDIX F14

HDPE FITTINGS

HDPE FITTINGS

This appendix demonstrates part of the results as only one (1) page of partial data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 2.4.1 – HDPE Fittings.

Table F14. 1
HDPE Fittings

Category	Contractor Qty	CMT Qty	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
CPVC ADAPTER	0	1	2 X 1.5	Ea	CPVC MALE ADAPTER, SOCKET X MNPT, F439-12, CELL 24448, D1784	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	1	2 X 0.5	Ea	CPVC REDUCING BUSHING, SPIGOT X FNPT, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	1	2 X 0.75	Ea	CPVC REDUCING BUSHING, SPIGOT X FNPT, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	2	2 X 1	Ea	CPVC REDUCING BUSHING, SPIGOT X SOCKET, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	1	2 X 1	Ea	CPVC REDUCING BUSHING, SPIGOT X FNPT, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	1	2 X 1.5	Ea	CPVC REDUCING BUSHING, MNPT X FNPT, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	3	2 X 1.5	Ea	CPVC REDUCING BUSHING, SPIGOT X SOCKET, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	2	3 X 0.75	Ea	CPVC REDUCING BUSHING, SPIGOT X FNPT, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	4	4 X 2	Ea	CPVC REDUCING BUSHING, SPIGOT X SOCKET, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	10	4 X 3	Ea	CPVC REDUCING BUSHING, SPIGOT X SOCKET, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC BUSHING	0	2	6 X 3	Ea	CPVC REDUCING BUSHING, SPIGOT X FNPT, F439-12, CELL 24448 [D1784]	P50	S80	11-Nov-15	S3
CPVC CAP	0	2	2.00	Ea	CPVC CAP, SOCKET, F439-12, CELL 24448, D1784	P50	S80	11-Nov-15	S3
CPVC CAP	0	7	1.50	Ea	CPVC CAP, FNPT, F437-09, CELL 24448, D1784	P50	S80	11-Nov-15	S3
CPVC CAP	0	2	1.50	Ea	CPVC CAP, SOCKET, F439-12, CELL 24448, D1784	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	28	0.75	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	5	1.00	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	10	1.50	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	1	2.00	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	2	3.00	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	19	4.00	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	7	8.00	Ea	CPVC COUPLING, SOCKET	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	1	2 X 1	Ea	CPVC REDUCING COUPLING, SOCKET X SOCKET F439-12, CELL 24448, D1784	P50	S80	11-Nov-15	S3
CPVC COUPLING	0	4	2 X 1.5	Ea	CPVC REDUCING COUPLING, SOCKET X SOCKET F439-12, CELL 24448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	26	0.75	Ea	CPVC ELBOW 90 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	1	0.75	Ea	CPVC ELBOW 45 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	5	1.00	Ea	CPVC ELBOW 90 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	2	1.00	Ea	CPVC ELBOW 45 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	1	1.50	Ea	CPVC ELBOW 45 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	2	1.50	Ea	CPVC ELBOW 90 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	4	2.00	Ea	CPVC ELBOW 90 DEG, FNPT X FNPT, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	6	3.00	Ea	CPVC ELBOW 90 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	1	3.00	Ea	CPVC ELBOW 45 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	1	4.00	Ea	CPVC ELBOW 45 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC ELBOW	0	6	8.00	Ea	CPVC ELBOW 45 DEG, SOCKET, F439-12, CELL 23448, D1784	P50	S80	11-Nov-15	S3
CPVC FLANGE	0	8	0.75	Ea	CPVC FLANGE (RF), SOCKET, F439-12, CELL 24448, D1784, CL150 B16.5 BOLT DRILLI	P50	80/150LB	11-Nov-15	S3
CPVC FLANGE	0	1	0.75	Ea	CPVC FLANGE (FF), SOCKET, F439-12, CELL 24448, D1784, CL150 B16.5 BOLT DRILLI	P50	80/150LB	11-Nov-15	S3
CPVC FLANGE	0	2	1.00	Ea	CPVC FLANGE (RF), SOCKET, F439-12, CELL 24448, D1784, CL150 B16.5 BOLT DRILLI	P50	80/150LB	11-Nov-15	S3

Dany Julien (2019)

APPENDIX F15

CPVC, HDPE, PVC FITTINGS

CPVC, HDPE, PVC FITTINGS

This appendix demonstrates part of the results as only one (1) page of partial data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 2.4.2 – CPVC, HDPE, PVC Fittings.

Table F15. 1
CPVC, HDPE, PVC Fittings

Category	Contractor Length	CMT Length	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
PIPE	0	20	1.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 23448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	80	1.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 23448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	40	2.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 23448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	12	4.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 24448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	54	4.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 24448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	36	6.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 24448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	100	8.000	Ft	CPVC PIPE, PE, F441/F441M-12, CELL 24448, D1784	P50	SCH80	11-Nov-15	BP Laydown
PIPE	0	10	1.500	Ft	HDPE - MUST VERIFY RATING		DR11?	11-Nov-15	BP Laydown
PIPE	0	0	2.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	280	700	3.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	80	200	4.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	180	400	6.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	20	50	8.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	90	120	10.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	40	140	12.00	Ft	HDPE - MUST VERIFY RATING	P71?	DR11?	11-Nov-15	BP Laydown
PIPE	2,000	2,000	0.75	Ft	HDPE ROLL, PE4710, ESTIMATED FOOTAGE - VERIFY	P71	DR11	11-Nov-15	BP Laydown
PIPE	1,400	1,400	1.00	Ft	HDPE ROLL, PE4710, ESTIMATED FOOTAGE - VERIFY	P70	DR9	11-Nov-15	BP Laydown
PIPE	2,500	2,500	1.00	Ft	HDPE ROLL, PE4710, ESTIMATED FOOTAGE - VERIFY	P71	DR11	11-Nov-15	BP Laydown
PIPE	1,200	1,200	1.50	Ft	HDPE ROLL, PE4710, ESTIMATED FOOTAGE - VERIFY	P70	DR9	11-Nov-15	BP Laydown
PIPE	450	450	2.00	Ft	HDPE ROLL, PE4710, ESTIMATED FOOTAGE - VERIFY	P71	DR11	11-Nov-15	BP Laydown
PIPE	8	0	2.00	Ft	IPS HDPE PIPE, PE4710 (ASTM D3035), CLASS: PE445574C (ASTM D3350), F714-15	P70	DR9	11-Nov-15	BP Laydown
PIPE	0	12	3.000	Ft	PVC	P40	SCH40	OCT 16 2015	BP PR 10
PIPE	0	40	4.000	Ft	PVC	P40	SCH80	OCT 16 2015	BP PR 10
PIPE	0	36	6.000	Ft	PVC	P40	SCH80	OCT 16 2015	BP PR 10
PIPE	0	100	6.000	Ft	PVC	P40	SCH80	OCT 16 2015	BP PR 10
PIPE	0	18	20.000	Ft	PVC	P40	SCH80	OCT 16 2015	BP PR 10
PIPE	0	50	1.000	Ft	WHITE PVC PIPE	P40	SCH40	OCT 16 2015	BP PR 10
PIPE	0	60	2.000	Ft	WHITE PVC PIPE	P40	SCH40	OCT 16 2015	BP PR 10
Total	8248	9,828							
Adjustment	-8								
sku	28								

Dany Julien (2019)

APPENDIX F16

STAINLESS STEEL FITTINGS

STAINLESS STEEL FITTINGS

This appendix demonstrates part of the results as only one (1) page of partial data is inserted below. Original documents for these Action Research results contain three (3) pages under the code 2.5.1 – Stainless Steel Fittings.

Table F16. 1
Stainless Steel Fittings

Category	Contractor Qty	CMT Qty	Size (In)	Description	Spec	Sch/Rat	Date Counted	Location
SS BLIND	2	0	1.500	BLIND - RF, B16.5 150#, 316LSS	P10	150	NOV 06 2015	S1 B17
SS BLIND	0	1	1.000	BLIND - RF, B16.5 150#, 316LSS	P10	150	Oct 4 2015	S1 B17
SS BLIND	23	21	2.000	BLIND - RF, B16.5 150#, 316LSS	P10	150	Oct 4 2015	S1 B18
SS BLIND	0	1	2.000	BLIND - RF, B16.5 300#, 316LSS	P10	300	Oct 4 2015	S1 B52
SS BLIND	12	0	2.000	BLIND - RF, B16.5 150#, 316LSS	P10	150	NOV 05 2015	
SS BLIND	1	1	2.000	BLIND - FF, B16.5 150#, 316LSS	N/A	150	Oct 4 2015	S1 B52
SS BLIND	0	5	2.000	BLIND - FF, B16.5 150#, 316LSS (C/W .75" NPT TAP ON CENTER)	P10	150	Oct 4 2015	S1 B52
SS BLIND	0	2	2.000	BLIND - RF, B16.5 150#, 316LSS (C/W 1" NPT TAP ON CENTER)	P10	150	Oct 4 2015	S1 B52
SS BLIND	24	24	2.000	BLIND - RF, B16.5 150#, 316LSS (C/W 1/2" NPT TAP ON CENTER)	P10	150	Oct 4 2015	S1 B52
SS BLIND	2	2	3.000	BLIND - RF, B16.5 150#, 316LSS	P10	150	Oct 4 2015	S1 B52
SS BLIND	1	0	3.000	BLIND - FF, B16.5 150#, 316LSS	N/A	150	NOV 06 2015	S1 B52
SS BLIND	0	1	3.000	BLIND - RF, B16.5 150#, 316LSS (C/W 2" NPT TAP ON CENTER)	P10	150	OCT 25 2015	S1 B17
SS BLIND	13	0	3.000	BLIND - RF, B16.5 150#, 316LSS (C/W 3" NPT TAP ON CENTER)	P10	150	NOV 05 2015	
SS BLIND	0	2	4.000	BLIND - RF, B16.5 150#, 316LSS	N/A	150	Oct 4 2015	S1 B16 / WH C12
SS BLIND	1	1	4.000	BLIND - FF, B16.5 150#, 316LSS	N/A	150	Oct 4 2015	S1 B18
SS BLIND	6	6	6.000	BLIND - RF, B16.5 150#, 316LSS	P10	150	Oct 4 2015	S1 B17
SS BLIND	1	1	6.000	BLIND - RF, B16.5 150#, 316LSS (C/W 3" NPT TAP ON CENTER)	P10	150	Oct 4 2015	S1 B17
SS BLIND	0	2	6.000	BLIND - RF, B16.5 150#, 316LSS	N/A	150	Oct 4 2015	S1 B17
SS BLIND	1	1	8.000	BLIND - FF, B16.5 150#, 316LSS	N/A	150	Oct 4 2015	S1 B17
SS BLIND	0	1	2.500	PADDLE BLIND - RF, B16.5 150#, 316LSS	P10	150	Oct 16 2015	S1 B32
SS BLIND	0	1	4.000	PADDLE BLIND - RF, B16.5 150#, 316LSS	P10	150	Oct 16 2015	S1 B32
SS BUSHING	6	6	1 X 0.5	BUSHING - 3000#, 316LSS	P10	3M	Oct 4 2015	S1 B3
SS BUSHING	25	25	2 x 0.75	BUSHING - 3000#, 316LSS	P10	3M	Oct 4 2015	S1 B3
SS BUSHING	1	0	2 x 1	BUSHING - 3000#, 316LSS	P10	3M	NOV 05 2015	
SS BUSHING	4	4	2 x 1.5	BUSHING - 3000#, 316LSS	P10	3M	Oct 4 2015	S1 B3
SS BUSHING	8	8	3 x 2	BUSHING - 3000#, 316LSS	P10	3M	Oct 4 2015	S1 B3
SS CAP	2	0	0.500	THREADED CAP - 3000#, FNPT, 316LSS	P10	3M	NOV 06 2015	
SS CAP	0	11	0.750	THREADED CAP - 3000#, FNPT, 316LSS	P10	3M	OCT 05 2015	S1 B3
SS CAP	23	23	1.000	THREADED CAP - 3000#, FNPT, 316LSS	P10	3M	OCT 05 2015	S1 B3
SS CAP	2	4	1.000	THREADED CAP - 3000#, FNPT, 316LSS	P10	3M	Oct 4 2015	S1 B25
SS CAP	0	1	2.000	THREADED CAP - 3000#, FNPT, 316LSS	P10	3M	Oct 4 2015	S1 B25
SS CAP	4	4	2.000	CAP - SCH10, BW, 316LSS	P12	SCH10	Oct 03 2015	S1 B 22
SS CAP	1	1	10.000	CAP - SCH10, BW, 316LSS	P12	SCH10	Oct 03 2015	S1 B 39

Dany Julien (2019)

APPENDIX F17

STAINLESS STEEL PIPING

STAINLESS STEEL PIPING

This appendix demonstrates part of the results as only one (1) page of data is inserted below. Original documents for these Action Research results contain one (1) page under the code 2.5.2 – Stainless Steel Piping.

Table F17. 1
Stainless Steel Piping

Category	Contractor Length	CMT Length	Size (In)	UoM	Description	Spec	Sch/Rat	Date Counted	Location
TUBING	240	0	0.50	Ft	1/2" OD x 0.049" Wall ASTM A213/A269 316L SS, SMLS	P11	N/A	NOV 06 2015	BP PR 28
TUBING	360	360	0.75	Ft	3/4" OD x 0.065" Wall ASTM A213/A269 316L SS, SMLS	P11	N/A	OCT 13 2015	BP PR 28
TUBING	240	60	0.38	Ft	3/8" OD x 0.065" Wall ASTM A213/A269 316L SS, SMLS	P11	N/A	OCT 13 2015	BP PR 28
PIPE	180	230	0.50	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH80	OCT 16 2015	BP PR 20
PIPE	0	260	0.75	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH 40	OCT 16 2015	BP PR 19
PIPE	40	60	0.75	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH80	OCT 16 2015	BP PR 19
PIPE	0	420	0.750	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	N/A	SCH40		
PIPE	80	50	1.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH80	OCT 13 2015	BP PR 19
PIPE	140	230	1.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH40	OCT 16 2015	BP PR 13
PIPE	20	0	1.00	FT	PIPE , SS A304	P10	SCH40	NOV 06 2015	
PIPE	20	0	1.25	Ft	PIPE , SS A304	P10	SCH40	NOV 06 2015	
PIPE	340	340	1.50	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH40	OCT 13 2015	BP PR 18/20
PIPE	100	60	2.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH80	OCT 16 2015	BP PR 17/18
PIPE	180	220	2.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR `18
PIPE	500	580	2.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH40	OCT 16 2015	BP PR 17
PIPE	20	20	3.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 16
PIPE	380	380	3.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH40	OCT 16 2015	BP PR 16
PIPE	220	220	4.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 12
PIPE	280	240	4.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH40	OCT 16 2015	BP PR 15
PIPE	0	30	6.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH 10	OCT 16 2015	BP PR 14
PIPE	0	6	6.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P10	SCH 40	OCT 16 2015	BP PR 14
PIPE	180	230	8.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 14
PIPE	0	10	10.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 11
PIPE	60	45	14.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 11
PIPE	40	16	16.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 11
PIPE	20	20	18.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 11
PIPE	40	40	18.00	Ft	PIPE, SS A312-TP316L, SMLS, BE, B36.19M	P12	SCH10	OCT 16 2015	BP PR 11
	3,680	4,127							
Adjustment	-280								
sku	27								

Dany Julien (2019)

APPENDIX G1

SEMI-STRUCTURED INTERVIEWS rev 0

SEMI-STRUCTURED INTERVIEWS rev 0

Doctoral Student: Dany Julien

Subject: The level of Supply Chain Robustness during Construction Mega-Projects

Introduction:

1. Confidentiality
2. Two-Phase Processes
   a. Semi-Structured Interview: Level II Metrics
      - ✓ Research Introduction and Constructs
      - ✓ Research Attributes
      - ✓ Level I Metrics
      - ✓ Level II Metrics
   b. Surveys on Level III Metrics - Later

<u>PROFILE</u>

Name of the Interviewee: ______________________
Function during the Project: ________________

List of Participants
- ☐ A. Member of the Project Team (Off-Site) – [redacted]
- ☐ B. Member of the Construction Management Team (At-Site) – [redacted]
- ☐ C.) Member of one of the Contractors (At-Site) – [redacted]
- ☐ D. Member of a Test Group – [redacted]

1. Type of semi-structured interview: ___ In person ____Telephone ____ Skype / Facetime / BBM

2. What age categories do you fall?

   a. Less than 30
   b. 30-39
   c. 40-49
   d. 50-59
   e. Above 59

3. How many years have you been working in the Engineering & Construction industry? ___________ years

4. Did you ever hold a trade before moving to E&C management? Yes - which one? ________ No ___

5. What functionalities did you have in the E&C process over the years? You may have more than one.

    a. Project Director
    b. Project Manager
    c. Construction Manager
    d. Engineers
    e. Field Engineers
    f. Planner
    g. Document Control
    h. Project Cost Control
    i. Contract Manager
    j. Procurement
    k. Leads – Civil
    l. Leads - Structural
    m. Leads – Mechanical
    n. Leads – Electrical
    o. Commissioning

6. Have you ever held a "supply chain function"? For instance, buyer, logistics, warehouse, transport, customs? Yes ____ No ____

<u>RESEARCH</u>

7. Did you read the research introduction before the interview? Yes, No Partially

8. Do you agree in the research findings (constructs)

    a. Status Quo in the Construction Industry
    b. Homogeneity in Mega-Project Management
    c. Change is always costly
    d. Uncertainty is common
    e. Reporting is executed on a Macro-Level
    f. Supply chain efficiency can never be achieved in construction project

<u>SCORE MODEL FOR ENGINEERING & CONSTRUCTION</u>

9. Did you ever hear of the SCORE Model?

<u>RESEARCH ATTRIBUTES</u>

10. Are the eight (8) attributes pertaining to the SCORE Model relevant to the E&C industry?

    a. Reliability

b. Responsiveness
c. Agility
d. Cost
e. Asset Management
f. Complexity
g. Maturity
h. Organisation

LEVEL I Metrics

11. Are the eleven (11) Level I Metrics pertaining to the SCORE Model relevant to the E&C industry?

a. Level I Metric: Delivery Performance & Perfect Purchase Order Fulfillment (%)
b. Level I: Purchase Order Fulfillment Cycle Time
c. Level I Metric: EPCM – Engineering Processes
d. Level I Metric: EPCM – Procurement Processes
e. Level I Metric: EPCM – Construction Processes
f. Level I Metric: EPCM – Management Processes
g. Level I Metric: SC Management Costs
h. Level I Metric: Leasing Equipment Cost
i. Level I Metric: Network Complexities
j. Level I Metric: Industry Maturity
k. Level I Metric: Organisational Readiness

LEVEL II METRICS

12. At what E&C phases that Level II Metrics are relevant? Measure the level of importance (1-5) of each Level II Metrics.

a. Phase I: Conceptual
b. Phase II: Front-End Engineering
c. Phase III: Detailed Engineering
d. Phase IV: Construction

MODIFIED SCORE MODEL: CONSTRUCTION SITE			Conceptual	Front-End Engineering	Detailed Engineering	Construction	Level of Importance (0 to 5)
Attributes	Level I Metrics	Level II Metrics	Y/N	Y/N	Y/N	Y/N	
Reliability	1. Delivery Performance & Perfect Purchase Order Fulfillment	1.1. Scheduled Orders Made by Owner's Request 1.2. Delivery Performance Against Owner's Requested Date 1.3. Delivery Performance by Suppliers' Committed Date 1.4. Perfect Order Fulfillment 1.5 Purchase Order Delivery, Quality & Accuracy 1.6 Bill of Materials Accuracy 1.7 Invoice Accuracy					
Responsiveness	2. Purchase Order Fulfillment Cycle Time	2.1 Purchase Order Entry Completed 2.2 Invoice Received at Owner 2.3 Inquiry Response Time - Procurement					
EPCM Agility	3. Engineering Processes 3. Procurement Processes 3. Construction Processes 3. Management Processes	3.10 Engineering Changes 3.11 Engineering Drawings 3.12 Engineering RFI 3.13 Engineering Cost Recovery 3.20 Conformities & Substitution 3.21 Material Management 3.22 Transportation Management 3.23 Equipment Management 3.24 Warehouse Management 3.25 Bagging / Expediting at Site 3.26 Reverse Logistics 3.30 Schedule Changes 3.31 Schedule Development 3.32 Schedule Performance					

		3.33 Planning Progress 3.34 Planning Milestone 3.35 Planning - FIWP 3.36 Commissioning 3.40 Document Control 3.41 Project Cost Control 3.42 Contract					
Costs	4. SC Management Cost 4. Cost of Goods Sold - NR in Pre-Constr.	4.1 Order Management Cost 4.2 Material Acquisition Cost 4.3 Inventory Carrying Cost 4.4 Planning Cost 4.5 IT Cost 4.6 Transportation Costs					
Asset Management	5. Cash-to-Cash Cycle Time 5. Return on SC Fixed Assets 5. Return on Working Capital	5.1 Inventory Turns - NR in Pre-Const. 5.2 Forecast Accuracy - NR in Pre-Const.					
Complexity	6. Configuration & Structure -Physical Product Flow 6. Processes & Systems in Place 6. Product & Services - NR in Pre-Const.	6.1 Manufacturing Complexity - NR in Pres-Const. 6.2 Distribution Complexity 6.3 Supplier Base Complexity 6.4 Customer (Contractor) Base Complexity 6.5 Complexity - related to IT					
Maturity	7. Overall SC Practice Maturity	7.1. Self-Assessed Practice - Strategy 7.2 Self-Assessed Practice – Plan (Pre-Construction) 7.3 Self-Assessed Practice – Source (Procurement) 7.4 Self-Assessed Practice – Make (Construction) 7.5 Self-Assessed Practice – Deliver (On Time, On Budget, Highest Quality) 7.6 Self-Assessed Practice - Return					
Organisation	8. Organisational Readiness	8.1 Presence of a Champion 8.2 Level of Analytics 8.3 Perceived Benefits 8.4 Perceived Performance Gap					

Level III Metrics

Level III Metrics consist of over 275 KPIs that were selected from various literatures or obtained over the last five years of research. The next phase of this research will be:

1. To prioritise Level I and II Metrics from the participants' answers
2. To identify which KPIs falls into these prioritise categories
3. Measures the essential KPI from a final survey.

APPENDIX G2

SEMI-STRUCTURED INTERVIEWS rev1

SEMI-STRUCTURED INTERVIEWS rev1

Doctoral Student: [redacted]

Subject: (Claude – Lequel?)

1. The level of Supply Chain Robustness during Construction Mega-Projects (not appealing to engineers)
2. Construction Performance: Can it be measured? Can it be modelized? (Est-ce ce terme est plus « neutral »)

Introduction:

1. Confidentiality (Claude, y'a-t-il un document à suivre?)

2. Semi-Structured Interview: Level II Metrics

    a. Research Introduction (Power Point Format – quick!)
        Industry Trend
        Constructs
        Literature: SCOR Model: not perfect but best model for construction

    b. Question Set # 1: SCOR Model
        1.1 SCOR Performance Attributes – are they relevant to construction?
        1.2 SCOR Level I Metrics – are they relevant to construction
        1.3 SCOR Level II Metrics – are they relevant to construction?
        1.4 Summary: SCOR Model – According to field staffs (not academia): is a relevant model for construction?

    c. Question Set # 2: Construction Performance Model: is a relevant model for construction?
        2.1 Performance Attributes – are they relevant to construction?
        2.2 Level I Metrics – are they relevant to construction
        2.2 Level II Metrics – are they relevant to construction?
        2.4 Summary: Construction Analytics – According to field staffs (not academia): is a relevant model for construction?

    d. List of Interviewees

Interview

Name of the Interviewee: ______________________

Job Title: ___________________________

 A. Member of the Project Team (Off-Site) – [redacted]

 B. Member of the Construction Management Team (At-Site) – relation to me…. CD CMT?

[redacted] C. Member of one of the Contractors (At-Site) – relation to me … [redacted]

[redacted] D. Member of a Test Group – relation to me… [redacted]

1. Type of semi-structured interview: ___ In person ____Telephone ____ Skype / Facetime / BBM

2. What **age** categories do you fall?
   a. Less than 30
   b. 30-39
   c. 40-49
   d. 50-59
   e. Above 59

3. How many **years** have you been working in the Engineering & Construction (E&C) industry? ___________ years

4. Did you ever hold a **trade** before moving to E&C management? Yes - which one? ________ No ___

5. What **job positions** have you held in your career? You may have more than one. Circle the letter.

   a. Project Director
   b. Project Manager
   c. Construction Manager
   d. Engineers
   e. Field Engineers
   f. Planner
   g. Document Control
   h. Project Cost Control
   i. Contract Manager
   j. Procurement

k. Leads – Civil
l. Leads - Structural
m. Leads – Mechanical
n. Leads – Electrical
o. Commissioning

6. Have you ever held a "**supply chain function**" in a construction project? For instance: procurement, buyer, logistics, warehouse, transport, customs? Yes ____ No ____ (Claude: Is this question relevant?)

RESEARCH

7. Did you read the research introduction before the interview? Yes___ No ___ (will review the PPT anyway in question 8)

8. Do you agree in the **Industry Trends, Constructs and Productivity**?

Manufacturing vs Construction		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Manufacturing vs Construction	**1**	**2**	**3**	**4**	**5**	**Remarks**
1	Construction projects are unique, non-routine and non-repetitive.						
2	In Mining and O&G projects, replication of activities are hard to implement.						
3	In Shipyard projects, replication of activities would be easier to implement.						
4	Manufacturing processes are highly automated, whereas construction processes are human-driven.						
5	Flow of Materials (BOM) is controlled in manufacturing, whereas BOM in construction constantly evolved and change.						
6	Information Technology in manufacturing is homogenous and powerful, whereas IT in construction is hetergenous and weak.						

Construction Constructs		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Constructs	1	2	3	4	5	Remarks
7	Construction is not manufacturing, hence supply chain efficiency will never be achieved						
8	Supply Chain Processes "as understood in most industries" is seen as "fragmented" in the Construction industry.						
9	Project Management techniques (ie. PMI) are homogeneous, in a sense, that PM and CM utilised the same techniques from projects to projects.						
10	Status Quo in the Construction Industry: The construction industry takes longer time to adopt new processes and technologies.						
11	Progres Reporting Are Executed on a Macro-Level. Manpower is not available to impement detailed statistics / analytics reportings.						
12	In construction, change is always view as costly.						
13	Uncertainty is common in Mega-Projects.						

Construction Productivity		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Productivity	1	2	3	4	5	Remarks
14	According to Ernst & Young, 64% of mega-projetcs suffers cost overruns.						
15	According to Ernst & Young., 73 of the mega-projects reported late completion.						
16	According to McKensey & Co., Productivity in manufacturing has nearly doubled (1.7x), whereas construction prouctivity has remained flat/sighlty decreased over the last 20 years.						

SCOR MODEL

In order to improve construction performance, the literature proposed the SCOR Model. Although the literature recognize the SCOR Model is not fully suitable for construction environment, it can assist in improving its performance.

9. Did you ever **heard** of the SCOR Model? Yes __ No ____

PERFORMANCE ATTRIBUTES

Explains why the "word supply chain" is used everywhere…. In manufacturing, materials (BOM) are tracked from suppliers – made – delivery - customers

10. Are the seven (7) **Performance Attributes** pertaining to the **SCOR Model** relevant to the E&C industry?

SCOR Model Performance Attributes		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Performance Attribute	**1**	**2**	**3**	**4**	**5**	**Remarks**
1	Supply Chain Reliability						
2	Supply Chain Responsiveness						
3	Supply Chain Agility						
4	Supply Chain Costs						
5	Supply Chain Asset Management						
6	Supply Chain Complexity						
7	Supply Chain Maturity						

Should I use the definition or just show Level I metrics? [redacted]

Reference no 1

	SCOR MODEL		
No.	Performance Attribute	Level 1 Metrics	Level II Metrics
1	Supply Chain Reliablity	Delivery Performance & Perfect Order Fulfilment (qty, %)	Scheduled Orders to Customer Request Delivery Performance to Request Date Delivery Performance to Commit Date Perfect Order Fulfillment
2	Supply Chain Responsiveness	Order Fulfilment Cycle Time (days)	Customer Signature / Authorisation to Order Receipt Order Receipt to Order Entry Complete Order Entry Complete to Start Pick/Pack of Order Start Pick/Pack of Order to Order Ready-to-Ship Order Ready-to-Ship to Customer Receipt of Order Customer Receipt of Order to Installation Complete
3	Supply Chain Agility	Upside SC Flexibility (days)	Upside Supply Chain (Source) Flexibiity Upside Suply Chain (Make) Flexibility
		Upside SC Adapatability (%)	Upside Supply Chain (Source) Adaptability Upside Suply Chain (Make) Adaptability
		Downside SC Flexibility (days)	Downside Supply Chain (Deliver) Flexibility
		Downside SC Adaptability (%)	Downside Supply Chain (Deliver) Adapatability

4	Supply Chain Costs	Total Costs to Serve	Order Management Cost Material Acquisition Cost Inventory Carrying Cost Supply Chain Related Finance, Planning & IT Costs
5	Supply Chain Assets Management	Cash-to-Cash Cycle Time	Inventory Days of Supply Raw Materials Inventory Days of Supply WIP Materials Inventory Days of Supply Finished Goods
		Return on SC Fixed Assets	Inventory Days of Supply - Finished Good Inventory Days of Supply - Raw Materials
		Return on Working Capital	Days Sales Outstanding Average Payment Period Total Inventory Days of Supply Cash-to-Cash Cycle Time (days)
6	Supply Chain Complexity	Physical Product Flow	Manufacturing Complexity Distribution and IT Centers Complexity Customer Base Complexity Supplier Base Complexity
		Process and System in Place	To Manage Sales & Operations Planning To Manage New Product Introduction To Manage Postponement and Configuration Strategy
		Product & Sales	Number of SKUs Offered Number of Annual Product Introduction Number of Finished Product Item Codes Number of Finished Product Purchased from 3rd Party New Product Introductions End of Life Product Retired During the Year Number of Promotional SKUs
7	Supply Chain Maturity	Self-Assessed Practices	Strategy, Plan, Source, Make, Deliver, Return

11. Are the seven (7) **Performance Attributes** pertaining to the **Construction Performance Model** relevant to the E&C industry?

Construction Performance Model Performance Attributes		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Performance Attribute	1	2	3	4	5	Remarks
1	Procurement Reliability						
2	Procurement Responsiveness						
3	EPCM Agility						
4	Project Controls						
5	Project Complexity						
6	Project Integration						
7	Project Analytics						

Reference no 2

	CONSTRUCTION PERFORMANCE MODEL		
No.	Performance Attribute	Level 1 Metrics	Level II Metrics
1	Procurement Reliability	1. Delivery Performance	1.1. Scheduled Purchase Orders Made by Owner's Request 1.2. Delivery Performance Against Owner's Requested Date 1.3. Delivery Performance by Suppliers' Committed Date 1.4. Perfect Orders' Fulfillment 1.5 Purchase Orders' Quality & Accuracy 1.6 Invoices' Accuracy
2	Procurement Responsiveness	2. Purchase Order Fulfillment Cycle Time	2.1 Purchase Order Entry Completed 2.2 Invoice Received at Owner 2.3 Inquiry Time - Procurement
3	EPCM Agility	3. EPCM Engineering	3.1 Engineering Changes 3.2 Engineering Drawings 3.3 Engineering RFI 3.4 Engineering Reworks 3.5 Quality - NCR
		4. EPCM Procurement	4.1 Material Management 4.2 Transportation Management 4.3 Leased Equipment Availability 4.4 Inventory Management 4.5 Bagging / Expediting at Site 4.6 Reverse Logistics
		5. EPCM Construction	5.1 Schedule (FIWP) Development 5.2 Schedule Changes 5.3 Site Performance 5.4 Turnover & Commissioning
		6. EPCM Management	6.1 Document Control 6.2 IT 6.3 Contract & Labour 6.4 Health, Safety & Environment
4	Project Controls	7. Budget & Planning	7.1 Budget 7.2 Earned and Burned Indicators
		8. LEM Spends	8.1 Labour & Management Spends 8.2 Material/ Equipment Spends 8.3 Rework Spends 8.4 IT Integration Spends
		9. Logistics Spends	9.1 Transportation Spends 9.2 Customs Spends 9.3 Warehouse / Laydown Spends 9.4 Inventory Carrying Costs
		10. Procurement Process Costs	10.1 Suppliers Spends 10.2 Purchase Order Costs
5	Power Analytics	13. Construction Analytics	13.1 Labour Force's Information 13.2 Management Information 13.3 Level II Metrics 13.4 Performance Analytics
6	Project Complexity	11. Off-Site Complexity	11.1 Manufacturing Complexity 11.2 Distribution Complexity 11.3 Supplier Base Complexity 11.4 IT Base Complexity
		12. Job Site Complexity	12.1 Contractor Base Complexity 12.2 Management Team / Owner Represetatives
7	Project Integration	Self-Assessed Practices	

12. In which **Project Phases** are these **Construction Performance Attributes** important?

Construction Performance Model Project Phases		Conceptual	Front-End Planning	Detailed Engineering	Construction	Closed Out	1 = Srongly Disagree 2 = Disagree 3 = Undecided 4 = Agree 5 = Strongly Agree
Performance Attribute		1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	Remarks
1	Procurement Reliability					N	
2	Procurement Responsiveness					N	
3	EPCM Agility					N	
4	Project Controls					N	
5	Project Complexity					N	
6	Project Integration					N	
7	Project Analytics					N	

LEVEL I METRICS

13. Following the results in Question no. 11 and reference no. 2; which **Level I Metrics** pertaining to the Construction Performance Model are relevant to the E&C industry?

Construction Performance Model Level I Metrics			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Performance Attribute	Level I Metrics	1	2	3	4	5	Remarks
1	Procurement Reliability							
		Delivery Performance						
2	Procurement Responsiveness							
		Purchase Order Fulfilment						
3	EPCM Agility							
		EPCM Engineering						
		EPCM Procurement						
		EPCM Construction						
		EPCM Management						
4	Project Controls							
		Budget & Planning						
		LEM Spends						
		Logistics Spends						
		Procurement Spends						
5	Project Complexity							
		Off-Site Complexity						
		Job Site Complexity						
6	Project Integration		N/A	N/A	N/A	N/A	N/A	
7	Project Analytics							
		Construction Analytics						

LEVEL II METRICS

14. Following the results in Question no. 13 and reference no. 2; which **Level II Metrics** pertaining to the Construction Performance Model are relevant to the E&C industry?

Construction Performance Model Level II Metrics		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Level I Metrics	Level II Metrics	1	2	3	4	5	Remarks
1	Delivery Performance						
	1.1. Scheduled Purchase Orders Made by Owner's Request						
	1.2. Delivery Performance Against Owner's Requested Date						
	1.3. Delivery Performance by Suppliers' Committed Date						
	1.4. Perfect Orders' Fulfillment						
	1.5 Purchase Orders' Quality & Accuracy						
	1.6 Invoices' Accuracy						
2	Purchase Order Fulfilment						
	2.1 Purchase Order Entry Completed						
	2.2 Invoice Received at Owner						
	2.3 Inquiry Time - Procurement						
3	EPCM Engineering						
	3.1 Engineering Changes						
	3.2 Engineering Drawings						
	3.3 Engineering RFI						
	3.4 Engineering Reworks						
	3.5 Quality - NCR						
	EPCM Procurement						
	4.1 Material Management						
	4.2 Transportation Management						
	4.3 Leased Equipment Availability						
	4.4 Inventory Management						
	4.4 Inventory Management						
	4.5 Bagging / Expediting at Site						
	4.6 Reverse Logistics						
	EPCM Construction						
	5.1 Schedule (FIWP) Development						
	5.2 Schedule Changes						
	5.3 Site Performance						
	5.4 Turnover & Commissioning						
	EPCM Management						
	6.1 Document Control						
	6.2 IT						
	6.3 Contract & Labour						
	6.4 Health, Safety & Environment						
4	Budget & Planning						
	7.1 Budget						
	7.2 Earned and Burned Indicators						
	LEM Spends						
	8.1 Labour & Management Spends						
	8.2 Material/ Equipment Spends						
	8.3 Rework Spends						
	8.4 IT Integration Spends						
	Logistics Spends						
	9.1 Transportation Spends						
	9.2 Customs Spends						
	9.3 Warehouse / Laydown Spends						
	9.4 Inventory Carrying Costs						
	Procurement Process Costs						
	Procurement Process Costs						
	10.1 Suppliers Spends						
	10.2 Purchase Order Costs						
5	Off-Site Complexity						
	11.1 Manufacturing Complexity						
	11.2 Distribution Complexity						
	11.3 Supplier Base Complexity						
	11.4 IT Base Complexity						
	Job Site Complexity						
	12.1 Contractor Base Complexity						
	12.2 Management Team / Owner Represetatives						
6	Project Integration - N/A						
7	Construction Analytics						
	13.1 Labour Force's Information						
	13.2 Management Information						
	13.3 Level II Metrics	N/A	N/A	N/A	N/A	N/A	
	13.4 Performance Analytics	N/A	N/A	N/A	N/A	N/A	

Level III Metrics (for the reader)

Level III Metrics consist of over 350 metrics that were selected from various literatures or obtained over the last five years of field research. The next phase of this research will be:

1. To prioritise Level I and II Metrics from the participants' answers
2. To identify which KPIs falls into these prioritise categories
3. Measures the essential KPI from a final survey.
4. Input progress reports + Project Analytics… Power BI

APPENDIX G3

SEMI-STRUCTURED INTERVIEWS rev 2.1

SEMI-STRUCTURED INTERVIEWS rev 2.1

Doctoral Student: Dany Julien

Subject: **Measuring the Degree of Performance Robustness during Construction Mega-Projects**

1. Non-Disclosure Agreement

Date: __________________ Time: _____________

Name of the Interviewee: ______________________

Job Title: ___________________________

 A. Member of the Project Team (At-Job-Site or Off-Site)
 B. Member of the Construction Management Team (At-Job-Site)
 C. Member of one of the Contractors (At-Job-Site)
 D. Member of a Test Group

1. Type **of interview**: ___ In person ____Telephone ____ Skype / Facetime / BBM

2. How many **years** have you been working in the Engineering & Construction (**E&C**) industry? ___________ years

3. Did you ever hold a **trade** before moving to E&C management? Yes - which one? ________ No ___

4. Most often, do you work on **Lump Sum Contract** or **Time & Materials Contract**?
   - What is your ratio? Lump Sum ______________ Time & Materials _______________

Part I: PREVIOUS FINDINGS: DBA 970

5. Do you agree in the **Industry Trends, Productivity and Constructs**?

Construction Productivity		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Productivity	1	2	3	4	5	Remarks
14	Large majorities (>51%) of mega-projects suffers cost overruns.						
15	Large majorities (>51%) of mega-projects report late completion.						
16	Over the last 20 years, Annual Productivity Growth (APG) in construction has only increased 1%, well below the manufactring APG (3.6%).						
17	Some accounting / research firms claim that construction indusry could improve 5-10x its productivity boost by moving to some (not all) of its processes to a manufacturing-style production system.						

Manufacturing vs Construction		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Manufacturing vs Construction		1	2	3	4	5	Remarks
1	Construction projects are unique, non-routine and non-repetitive.						
2	In Mining and O&G projects, replication of activities are hard to implement.						
3	In Shipyard projects, replication of activities would be easier to implement.						
4	Manufacturing processes are highly automated, whereas construction processes are human-driven.						
5	Flow of Materials (BOM) is controlled in manufacturing, whereas BOM in construction constantly evolved and change.						
6	Information Technology in manufacturing is homogenous and powerful, whereas IT in construction is hetergenous and weak.						

Construction Constructs		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Constructs	1	2	3	4	5	Remarks
7	Construction is not Manufacturing, hence supply chain efficiency will never be achieved.						
8	Supply Chain Processes "as understood in most industries" is seen as "fragmented" in the Construction industry.						
9	Project Management techniques (ie. PMI) are homogeneous, in a sense, that PM and CM utilised the same approaches / techniques from projects to projects.						
10	Status Quo in the Construction Industry: The construction industry takes longer time to adopt new processes and technologies.						
11	Progress Reporting are reported on a Macro-Level. Manpower is not available to impement detailed statistics / analytics reportings.						
12	In construction, change is always view as costly.						
13	Uncertainty is common in Mega-Projects.						

PART II: HOW CAN WE IMPROVE CONSTRUCTION PRODUCTIVITY?

SCOR MODEL (SUPPLY CHAIN OPERATIONS REFERENCE)

Note: The SCOR Model combines elements of business process engineering, metrics, benchmarking, leading practices and people skills into a single framework.

Although the SCOR Model is one of the best supply chain integrated tool to understand organisations' internal and external processes in many industries, the literature recognizes its weakness when applied to the Construction industry.

This research has adopted the SCOR Model into a **Construction Performance Model**, suited for construction mega-projects.

Note: SCOR Model is made up of 7 Performance Attributes (categories) which are subdivided in Level I, II and III metrics.

6. Have you ever **heard** of the SCOR Model? Yes __ No ____

PERFORMANCE ATTRIBUTES

Note: the original **SCOR Performance Attributes** have been **modified** to reflect the **Construction Performance Model**.

7. Do you think the seven (7) **Performance Attributes** presented below pertain to evaluate performance (**Construction Performance Model)** in the E&C industry?

Construction Performance Model Performance Attributes		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Performance Attribute		1	2	3	4	5	Remarks
1	Procurement Reliability						
2	Procurement Responsiveness						
3	EPCM Agility						
4	Project Controls						
5	Workers (Asset) Management						
6	Project Complexity						
7	Project Integration						

- **Procurement Reliability**: The performance of the Procurement Department in **delivering** the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct warehouse / laydown.
- **Procurement Responsiveness**: The speed at which Procurement provides products to its Engineering / Construction Team. This is the average actual cycle time (days) consistently achieved to fulfill customer order.
- **EPCM Agility**: The ability, flexibility and adaptability for the four "4" groups (Engineering, Procurement, Construction, Management) to respond to external and internal influences, the ability to respond to changes, to maintain or improve the project's scope objectives (deliver on time, on budget at highest quality).
- **Project Controls**: The cost associated with operating a Project.
- **Workers (Asset) Management**: The effectiveness of an organisation in managing its primary asset (Labor Force + Managerial Staffs) in order to maintain or improve the project's scope objectives (deliver on time, on budget and at the highest quality).
- **Project Complexity**: The complexity of a project is assessed along two dimensions (Off-Site and at Job-Site). High levels of project complexity, left unmanaged, reduce operational performance and lead to higher costs
- **Project Integration**: The framework evaluates how well your project team is integrating the Performance Attributes into multiple phases (from conception to closed out) of the project.

LEVEL I METRICS

8. Following the results in Question no. 7; which **Level I Metrics** pertaining to the Performance Attributes are relevant to the E&C industry?

Construction Performance Model Level I Metrics		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Perf. Att.	**Level I Metrics**	**1**	**2**	**3**	**4**	**5**	**Remarks**
1	Procurement Reliability						
	1. Delivery Performance						
2	Procurement Responsiveness						
	2. Purchase Order Fulfilment						
3	EPCM Agility						
	3. Engineering						
	4. Procurement						
	5. Construction						
	6. Management						
4	Project Controls						
	7. Budget & Planning						
	8. LEM Spends						
	9. Logistics Spends						
	10. Procurement Spends						
5	Workers (Asset) Management						
	11. Workers Information						
6	Project Complexity						
	12. Off-Site Complexity						
	13. Job Site Complexity						
	14. Performance Analytics						
7	Project Integration	N/A	N/A	N/A	N/A	N/A	

Note 1: Examples of Delivery Performance metrics
- Delivery Performance by committed date
- Invoice Accuracy

Note 2: Examples of Purchase Order Fulfilment metrics
- Inquire Time to respond

Note 3: Examples of Engineering metrics
- RFI, Change Order, NCR, etc.

Note 4: Examples of Procurement metrics
- MRR, OSD, Free Issue, etc.

Note 5: Examples of Construction metrics
- Schedule changes and delays, FIWP

Note 6: Examples of Management metrics
- Document control, Safety metrics

Note 7: Examples of Budget & Planning metrics
- Earned vs Burned

Note 8: Examples of LEM Spends metrics
- Labour, Equipment and Materials Spends

Note 9: Examples of Logistics Spends metrics
- Transportation and customs Spends

Note 10: Examples of Procurement Spends metrics
- Suppliers Spends

Note 11: Examples of Workers Information metrics
- Labour + Management information

Note 12: Examples of Off-Site Complexity metrics
- Suppliers / Distributors' location

Note 13: Examples of Job-Site Complexity metrics
- Contractors' Base
- Number of area under construction at once

Note 14: Examples of Construction Analytics metrics
- Importing Key KPI for dashboard
- Importing 350+KPI for data mining

LEVEL II METRICS

9. Following the results in Question no. 8; which **Level II Metrics** pertaining to the Construction Performance Model are relevant to the E&C industry?

Construction Performance Model Level II Metrics		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Level I	**Level II**	**1**	**2**	**3**	**4**	**5**	**Remarks**
1	Delivery Performance						
	1.1. Scheduled Purchase Orders Made by Owner's Request						
	1.2. Delivery Performance Against Owner's Requested Date						
	1.3. Delivery Performance by Suppliers' Committed Date						
	1.4. Perfect Orders' Fulfillment						
	1.5 Purchase Orders' Quality & Accuracy						
	1.6 Invoices' Accuracy						
2	Purchase Order Fulfilment						
	2.1 Purchase Order Entry Completed						
	2.2 Invoice Received at Owner						
	2.3 Inquiry Time - Procurement						
3	Engineering						
	3.1 Engineering Changes						
	3.2 Engineering Drawings						
	3.3 Engineering RFI						
	3.4 Engineering Reworks						
	3.5 Quality - NCR						
4	Procurement						
	4.1 Material Management						
	4.2 Transportation Management						
	4.3 Leased Equipment Availability						
	4.4 Inventory Management						
	4.5 Bagging / Expediting at Site						
	4.6 Reverse Logistics						
5	Construction						
	5.1 Schedule (FIWP) Development						
	5.2 Schedule Changes						
	5.3 Site Performance						
	5.4 Turnover & Commissioning						
6	Management						
	6.1 Document Control						
	6.2 IT						
	6.3 Contract & Labour						
	6.4 Health, Safety & Environment						

7	Budget & Planning						
	7.1 Budget						
	7.2 Earned and Burned Indicators						
8	LEM Spends						
	8.1 Labour & Management Spends						
	8.2 Material/ Equipment Spends						
	8.3 Rework Spends						
	8.4 IT Integration Spends						
9	Logistics Spends						
	9.1 Transportation Spends						
	9.2 Customs Spends						
	9.3 Warehouse / Laydown Spends						
	9.4 Inventory Carrying Costs						
10	Procurement Spends						
	10.1 Suppliers Spends						
	10.2 Purchase Order Costs						
11	Workers Information						
	11.1 Labour Force's Information						
	11.2 Management Information						
12	Off-Site Complexity						
	12.1 Manufacturing Complexity						
	12.2 Distribution Complexity						
	12.3 Supplier Base Complexity						
	12.4 IT Base Complexity						
13	Job Site Complexity						
	13.1 Contractor Base Complexity						
	13.2 Management Team / Owner Represetatives						
14	Performance Analytics						
	14.1 Level II Metrics						
	14.2 Performance Analytics						
15	Project Integration - N/A						

10. In which **Project Phases** are these **Construction Performance Attributes** important?

Construction Performance Model Project Phases		Conceptual	Front-End Planning	Detailed Engineering	Construction	Closed Out	1 = Srongly Disagree 2 = Disagree 3 = Undecided 4 = Agree 5 = Strongly Agree
Performance Attribute		1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	Remarks
1	Procurement Reliability					N/A	
2	Procurement Responsiveness					N/A	
3	EPCM Agility					N/A	
4	Project Controls					N/A	
5	Workers (Asset) Management					N/A	
6	Project Complexity					N/A	
7	Project Integration					N/A	

Level III Metrics (to follow)

Level III Metrics consist of over 350+ metrics that were selected from various literatures or obtained over the last five years of field research. The next phase of this research will be:

1. To prioritise Level I and II Metrics from the participants' answers
2. To identify which metrics falls into these prioritised categories through Monkey Survey.
3. Measures the essential KPI from a final survey.

Thank you for your time and consideration.

Dany Julien, M.Sc. Logistics
Doctorant au DBA - Université de Sherbrooke

APPENDIX G4

SEMI-STRUCTURED INTERVIEWS rev 2.2

SEMI-STRUCTURED INTERVIEWS rev 2.2

Doctoral Student: Dany Julien

Subject: **Measuring the Degree of Performance and Productivity Robustness during Construction Mega-Projects**

1. Review of the Information & Consent Form (Université de Sherbrooke)

2. The Interview

Date: ___________________ Time: ______________

Name of the Interviewee: _______________________

Job Title: ____________________________
- ☐ A. Member of the Project Team (At-Job-Site or Off-Site)
  - ☐ B. Member of the Construction Management Team (At-Job-Site)
    - ☐ C. Member of one of the Contractors (At-Job-Site)
      - ☐ D. Member of a Test Group

1. Type **of interview**: ___ In person ____Telephone ____ Skype / Facetime / BBM

2. How many **years** have you been working in the Engineering & Construction (**E&C**) industry? ____________ years

3. Did you ever hold a **trade** before moving to E&C management? Yes - which one? ________ No ___

4. Most often, do you work on **Lump Sum Contract** or **Time & Materials Contract?**
   - What is your ratio? Lump Sum _______________ Time & Materials ________________

Part I: PREVIOUS FINDINGS: DBA 970

5. Do you agree in the **Industry Trends, Productivity and Constructs**?

Construction Productivity		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Productivity	1	2	3	4	5	Remarks
14	Large majorities (>51%) of mega-projects suffers cost overruns.						
15	Large majorities (>51%) of mega-projects report late completion.						
16	Over the last 20 years, Annual Productivity Growth (APG) in construction has only increased 1%, well below the manufactring APG (3.6%).						
17	Some accounting / research firms claim that construction indusry could improve 5-10x its productivity boost by moving to some (not all) of its processes to a manufacturing-style production system.						

Manufacturing vs Construction		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Manufacturing vs Construction	1	2	3	4	5	Remarks
1	Construction projects are unique, non-routine and non-repetitive.						
2	In Mining and O&G projects, replication of activities are hard to implement.						
3	In Shipyard projects, replication of activities would be easier to implement.						
4	Manufacturing processes are highly automated, whereas construction processes are human-driven.						
5	Flow of Materials (BOM) is controlled in manufacturing, whereas BOM in construction constantly evolved and change.						
6	Information Technology in manufacturing is homogenous and powerful, whereas IT in construction is hetergenous and weak.						

Construction Constructs		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
	Constructs	1	2	3	4	5	Remarks
7	Construction is not Manufacturing, hence supply chain efficiency will never be achieved.						
8	Supply Chain Processes "as understood in most industries" is seen as "fragmented" in the Construction industry.						
9	Project Management techniques (ie. PMI) are homogeneous, in a sense, that PM and CM utilised the same approaches / techniques from projects to projects.						
10	Status Quo in the Construction Industry: The construction industry takes longer time to adopt new processes and technologies.						
11	Progress Reporting are reported on a Macro-Level. Manpower is not available to impement detailed statistics / analytics reportings.						
12	In construction, change is always view as costly.						
13	Uncertainty is common in Mega-Projects.						

PART II: HOW CAN WE IMPROVE CONSTRUCTION PRODUCTIVITY?

SCOR MODEL (SUPPLY CHAIN OPERATIONS REFERENCE)

Note: The SCOR Model combines elements of business process engineering, metrics, benchmarking, leading practices and people skills into a single framework.

Although the SCOR Model is one of the best supply chain integrated tool to understand organisations' internal and external processes in many industries, the literature recognizes its weakness when applied to the Construction industry.

This research has adopted the SCOR Model into a **Construction Performance Model**, suited for construction mega-projects.

Note: SCOR Model is made up of 7 Performance Attributes (categories) which are subdivided in Level I, II and III metrics.

6. Have you ever **heard** of the SCOR Model? Yes __ No ____

PERFORMANCE ATTRIBUTES

Note: the original **SCOR Performance Attributes** have been **modified** to reflect the **Construction Performance Model**.

7. Do you think the seven (7) **Performance Attributes** presented below pertain to evaluate performance (**Construction Performance Model)** in the E&C industry?

Construction Performance Model Performance Attributes		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Performance Attribute		1	2	3	4	5	Remarks
1	Procurement Reliability						
2	Procurement Responsiveness						
3	EPCM Agility						
4	Project Controls						
5	Workers (Asset) Management						
6	Project Complexity						
7	Project Integration						

- **Procurement Reliability:** The performance of the Procurement Department in **delivering** the correct product to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct warehouse / laydown.

- **Procurement Responsiveness:** The speed at which Procurement provides products to its Engineering / Construction Team. This is the average actual cycle time (days) consistently achieved to fulfill customer order.
- **EPCM Agility**: The ability, flexibility and adaptability for the four "4" groups (Engineering, Procurement, Construction, Management) to respond to external and internal influences, the ability to respond to changes, to maintain or improve the project's scope objectives (deliver on time, on budget at highest quality).
- **Project Controls:** The cost associated with operating a Project.
- **Workers (Asset) Management**: The effectiveness of an organisation in managing its primary asset (Labor Force + Managerial Staffs) in order to maintain or improve the project's scope objectives (deliver on time, on budget and at the highest quality).
- **Project Complexity**: The complexity of a project is assessed along two dimensions (Off-Site and at Job-Site). High levels of project complexity, left unmanaged, reduce operational performance and lead to higher costs
- **Project Integration**: The framework evaluates how well your project team is integrating the Performance Attributes into multiple phases (from conception to closed out) of the project.

LEVEL I METRICS

8. Following the results in Question no. 7; which **Level I Metrics** pertaining to the Performance Attributes are relevant to the E&C industry?

Construction Performance Model Level I Metrics		Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
Perf. Att.	Level I Metrics	1	2	3	4	5	Remarks
1	Procurement Reliability						
	1. Delivery Performance						
2	Procurement Responsiveness						
	2. Purchase Order Fulfilment						
3	EPCM Agility						
	3. Engineering						
	4. Procurement						
	5. Construction						
	6. Management						
4	Project Controls						
	7. Budget & Planning						
	8. LEM Spends						
	9. Logistics Spends						
	10. Procurement Spends						
5	Workers (Asset) Management						
	11. Workers Information						
6	Project Complexity						
	12. Off-Site Complexity						
	13. Job Site Complexity						
	14. Performance Analytics						
7	Project Integration	N/A	N/A	N/A	N/A	N/A	

Note 1: Examples of Delivery Performance metrics
- Delivery Performance by committed date
- Invoice Accuracy

Note 2: Examples of Purchase Order Fulfilment metrics
- Inquire Time to respond

Note 3: Examples of Engineering metrics
- RFI, Change Order, NCR, etc.

Note 4: Examples of Procurement metrics
- MRR, OSD, Free Issue, etc.

Note 5: Examples of Construction metrics
- Schedule changes and delays, FIWP

Note 6: Examples of Management metrics
- Document control, Safety metrics

Note 7: Examples of Budget & Planning metrics
- Earned vs Burned

Note 8: Examples of LEM Spends metrics
- Labour, Equipment and Materials Spends

Note 9: Examples of Logistics Spends metrics
- Transportation and customs Spends

Note 10: Examples of Procurement Spends metrics
- Suppliers Spends

Note 11: Examples of Workers Information metrics
- Labour + Management information

Note 12: Examples of Off-Site Complexity metrics
- Suppliers / Distributors' location

Note 13: Examples of Job-Site Complexity metrics
- Contractors' Base
- Number of area under construction at once

Note 14: Examples of Construction Analytics metrics
- Importing Key KPI for dashboard
- Importing 350+KPI for data mining

LEVEL II METRICS

9. Following the results in Question no. 8; which **Level II Metrics** pertaining to the Construction Performance Model are relevant to the E&C industry?

Performance Attributes	Level I	Construction Performance Model Level II Metrics	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	
		Level II	1	2	3	4	5	Remarks
1	1	Delivery Performance						
		1.1. Scheduled Purchase Orders Made by Owner's Request						
		1.2. Delivery Performance Against Owner's Requested Date						
		1.3. Delivery Performance by Suppliers' Committed Date						
		1.4. Perfect Orders' Fulfillment						
		1.5 Purchase Orders' Quality & Accuracy						
		1.6 Invoices' Accuracy						
2	2	Purchase Order Fulfilment						
		2.1 Purchase Order Entry Completed						
		2.2 Invoice Received at Owner						
		2.3 Inquiry Time - Procurement						
3	3	Engineering						
		3.1 Engineering Changes						
		3.2 Engineering Drawings						
		3.3 Engineering RFI						
		3.4 Engineering Reworks						
		3.5 Quality - NCR						

3	4	Procurement						
		4.1 Material Management						
		4.2 Transportation Management						
		4.3 Leased Equipment Availability						
		4.4 Inventory Management						
		4.5 Bagging / Expediting at Site						
		4.6 Reverse Logistics						
3	5	Construction						
		5.1 Schedule (FIWP) Development						
		5.2 Schedule Changes						
		5.3 Site Performance						
		5.4 Turnover & Commissioning						
3	6	Management						
		6.1 Document Control						
		6.2 IT						
		6.3 Contract & Labour						
		6.4 Health, Safety & Environment						
4	7	Budget & Planning						
		7.1 Budget						
		7.2 Earned and Burned Indicators						
4	8	LEM Spends						
		8.1 Labour & Management Spends						
		8.2 Material/ Equipment Spends						
		8.3 Rework Spends						
		8.4 IT Integration Spends						
4	9	Logistics Spends						
		9.1 Transportation Spends						
		9.2 Customs Spends						
		9.3 Warehouse / Laydown Spends						
		9.4 Inventory Carrying Costs						
4	10	Procurement Spends						
		10.1 Suppliers Spends						
		10.2 Purchase Order Costs						
5	11	Workers Information						
		11.1 Labour Force's Information						
		11.2 Management Information						
6	12	Off-Site Complexity						
		12.1 Manufacturing Complexity						
		12.2 Distribution Complexity						
		12.3 Supplier Base Complexity						
		12.4 IT Base Complexity						
6	13	Job Site Complexity						
		13.1 Contractor Base Complexity						
		13.2 Management Team / Owner Represetatives						
6	14	Performance Analytics						
		14.1 Level II Metrics						
		14.2 Performance Analytics						
7	15	Project Integration - N/A						

10. In which **Project Phases** are these **Construction Performance Attributes** important?

	Construction Performance Model **Project Phases**	Conceptual	Front-End Planning	Detailed Engineering	Construction	Closed Out	1 = Srongly Disagree 2 = Disagree 3 = Undecided 4 = Agree 5 = Strongly Agree
	Performance Attribute	1 to 5	1 to 5	1 to 5	1 to 5	1 to 5	**Remarks**
1	Procurement Reliability					N/A	
2	Procurement Responsiveness					N/A	
3	EPCM Agility					N/A	
4	Project Controls					N/A	
5	Workers (Asset) Management					N/A	
6	Project Complexity					N/A	
7	Project Integration	N/A	N/A	N/A	N/A	N/A	

Level III Metrics

Level III Metrics consist of over 350+ metrics that were selected from various literatures or obtained over the last five years of field research. The next phase of this research will be:

1. To prioritise Level I and II Metrics from the participants' answers
2. To identify which metrics falls into these prioritised categories through Monkey Survey.
3. Measures the essential KPI from a final survey.

Thank you for your time and consideration.

Dany Julien, M.Sc. Logistics
Doctorant au DBA - Université de Sherbrooke

APPENDIX H

LETTER OF INVITATION

LETTERS OF INVITATION

Letter of Invitation – (Interview)

20 June 2018 (Sherbooke, QC)

Dear Participant,

As you were aware over the past five years, I have been conducting a doctoral research in the attempt to understand why mega-projects are so often realized over budget and turnover late.

The objective of this interview is to identify which performance and productivity metrics should be measured during the execution of mega-projects. By participating in this interview, you and I will help in the advancement of construction management.

The interview will be conducted under your own time and I will make myself available according to your schedule. I will contact you in the 48 hours to set up a time.

Additionally, in order to maximize your valuable time, I have attached the Semi-Structured Interview. You will note the interview has three sections:

- **Section I**: Validate some construction constructs
- **Section II**: Measure the level of performance and productivity robustness from a new model that I'm proposing (Construction Performance & Productivity Model)
- **Section III**: Measures the level of integration of each performance attribute throughout the project phases.

The scaling evaluation for the Performance Attribute / Level I group / Level II metrics is based on a Likert scale scores and are as followed:

1. **Strongly Agree**. This Performance Attribute / Level I group / Level II metrics are very important.
2. **Agree**. This Performance Attribute / Level I group / Level II metrics are important.
3. **Undecided**. This Performance Attribute / Level I group / Level II metrics are important at time / and other time not important.
4. **Disagree**. This Performance Attribute / Level I group / Level II metrics are rarely important.
5. **Strongly Disagree**. This Performance Attribute / Level I group / Level II metrics are not important at all.

In addition, I have attached the Information and Consent Form. Please read it, sign it and return only the signature page (p.4)

Once again, I would like to thank you for participating in my research.

[redacted]
Doctoral Student
Université de Sherrooke

Note 1: Once the results from the interviews are tabulated, I will forward the metrics that display the most robustness in performance and productivity for the seven (7) Performance Attributes.

Letter of Invitation – (Survey)

August 16th, 2018 (Sherbooke, QC)

Dear Participant,

First of all, I would like to thank you for participating in the interviews. As discussed with all of you, the survey is the last step of my research, before I start drafting the final thesis for my research.

The objective of this survey is to identify the final top performance attributes and metrics amongst four types of contracts. Furthermore, the survey is divided into four sections, and there is no time limit allocated for answering the questions.

- **Q1**. When Owners are constructing mega-projects ($300M+) and operating under "LUMP SUM / DESIGN BUILT CONTRACT", which metrics would you consider measuring?
- **Q2**. When Owners are constructing mega-project ($300M+) and operating under "TIME MATERIALS / COSTS +% CONTRACT", which metrics would you consider measuring?
- **Q3**. When Contractors are constructing mega-project ($300M+) and operating under "LUMP SUM / DESIGN BUILT CONTRACT", which metrics would you consider measuring?
- **Q4**. When Contractors are constructing mega-project ($300M+) and operating under "TIME MATERIALS / COSTS +% CONTRACT", which metrics would you consider measuring?

The scaling evaluations for the Performance Attribute / Level I group / Level II metrics are based on a Likert scale as followed:

1. **Strongly Agree**. This Performance Attribute / Level I group / Level II metrics are very important.
2. **Agree**. This Performance Attribute / Level I group / Level II metrics are important.
3. **Undecided**. This Performance Attribute / Level I group / Level II metrics are important at time / and other time not important.
4. **Disagree**. This Performance Attribute / Level I group / Level II metrics are rarely important.
5. **Strongly Disagree**. This Performance Attribute / Level I group / Level II metrics are not important at all.

Once again, I would like to thank you for participating in my research.

[redacted]
Doctoral Student
Université de Sherbrooke

APPENDIX I

INFORMATION & CONSENT FORM

INFORMATION & CONSENT FORM

INFORMATION AND CONSENT FORM

You are invited to participate in a research study. This document describes the study procedures. Feel free to ask questions about any words or paragraphs you do not understand.

The interview will be conducted under your own time and I will make myself available according to your schedule. In order to take part in the study, you must sign the consent section at the end of this document; a signed and dated copy will be returned to you. Please take all the time you need to make your decision.

Research Study Title

Measuring the Level of Performance and Productivity Robustness during Construction Mega-Projects: A Design Science Research

Researcher Responsible for the Research Study

Dany Julien, doctorate student
Système d'information et méthodes quantitatives de gestion (SIMQG)
Département SIMQG, École de gestion, Université de Sherbrooke
For more information, you may contact the researcher by phone at [redacted] or at [redacted].

Claude Caron, professeur titulaire, Département SIMQG, École de gestion, Université de Sherbrooke. For more information, you may contact the researcher by phone at [redacted] or by email at [redacted]

Purpose of the Research Study [redacted]

The purpose of this study is to measure the level of performance and productivity robustness during construction mega-projects.

A series of performance attributes and metrics will be presented to you, whereas you will select (Likert scale) which metrics should be retained or rejected. The end-final result will be the development of a model (tool) that will be measuring performance and productivity metrics.

The name of the research model is titled: Construction Performance & Productivity Model.

Description of the Research Procedures

Your implication for this project involves two phases.

The first part involve a **semi-structured interview, whereas the participant will respond to questions with the researcher** in person, by Skype, by Facetime, or by phone. The semi-structured will take approximately 45 to 60 minutes. The objective of this semi-structured interview is to measure performance and productivity attributes during a mega-project. Once rated in terms of importance, the performance and productivity attributes will be segmented in three subgroups, which are Level I, II and III metrics.

The second phase of this research will involve answering a **survey** in order to differentiate which performance and productivity attributes are to be used during Lump Sum (Design-Build) Contracts and/or Time & Material Contracts. This survey should take approximately 15 to 20 minutes.

You have been invited to take part in this research study because you (1) have acquired experience in managing large construction mega-project, (2) have worked in the mining, oil & gas, infrastructure and energy sectors, (3) have experience in complex project management, and (4) have experience in construction management.

Potential Benefits

By participating in this project, you will contribute to the advancement of knowledge in the field of **Construction Management** and **Management Information System**.

Moreover, by participating in this project, you will contribute in building a construction model that will be friendly to use during mega-project.

Potential Risks

Your participation should not involve any significant inconveniences, other than taking up some of your time. You may ask to take a break or to continue the interview at a more convenient time.

You name will remain private and confidential to the researcher of this project.

Voluntary Participation and the Right to Withdraw

Your participation in this research project is voluntary. Therefore, you may refuse to participate. You may also withdraw from the project at any time, without giving any reason, by informing a member of the research team.

AND

If you withdraw or are withdrawn from the study, the information collected during the study will note be stored, analyzed or used to protect the scientific integrity of the research project and the participants.

In this eventuality of a participant withdrawing, the researcher will validate your preferences regarding data destruction.

Confidentiality

During your participation in this study, the researcher responsible and the research team will collect and record information about you in a study file. They will only collect information required to meet the scientific goals of the study.

Your research file may include information such as your name and a code associated to your name, and recording notes of the interviews.

All the information collected during the research project will remain confidential to the extent provided by law. As stated above, you will only be identified by a code number. The researcher responsible for this study will keep the key to the code linking your name to your study file.

The study data will be stored for 5 years by the researcher responsible for this study for research purposes as described in this information and consent form.

The data may be published or shared during scientific meetings; however, it will not be possible to identify you.

For monitoring and control, your study file may be examined by a person mandated by regulatory authorities, as well as by representatives of the funding agency, the institution, or the Research Ethics Board. All these individuals and organizations adhere to policies on confidentiality.

You have the right to consult your study file in order to verify the information gathered, and to have it corrected if necessary.

Study Results

The study results will be available in June 2018, and a synopsis of it will be sent to you.

Contact Information

If you have questions or if you have a problem you think may be related to your participation in this research study, or if you would like to withdraw, you may communicate with the researcher responsible of this research study or with someone on the research team at the following number: [redacted]

Approval of the Research Ethics Board

The Research Ethics Board of the Université de Sherbrooke (CÉR Lettres et sciences humaines) approved this research and is responsible for the monitoring of the study.

For any question concerning your rights as a research participant taking part in this study, or if you have comments, or wish to file a complaint, you may communicate with the Research Ethics Board at the following phone number [redacted] (or toll free at [redacted]) extension [redacted], or by email at cer_lsh@USherbrooke.ca.

Signature of the Participant

I have reviewed the information and consent form. Both the research study and the information and consent form were explained to me. My questions were answered, and I was given sufficient time to make a decision. After reflection, I consent to participate in this research study in accordance with the conditions stated above.

Name of participant Signature Date

Commitment of the Researcher Responsible of the Research Study

I certify that this information and consent form were explained to the research participant, and that the questions the participant had were answered.

I undertake, together with the research team, to respect what was agreed upon in the information and consent form, and to give a signed and dated copy of this form to the research participant.

Dany Julien 24 June 2018

Name of the Researcher Responsible Signature Date

APPENDIX J

PARTICIPANTS' PROFILES

PARTICIPANTS' PROFILES

Table J. 1 Participants' Profiles
Participants' Profiles

Participippants Codes	Status	Age Group	Job Title	In Person	Telephone	Skype	Location	How many Years in E&C	How many years of working in its speciality	Have a Trade	Trade	Lump Sum Contract	Time & Materials Contract	Start Time - Interview	Finish Time - Interview	Duration of the Interview
1	CMT	2	Construction Manager		X		ON	20	20	Y	Electrician	30%	70%	20:00	20:50	0:50
2	CMT	3	Project Manager		X		ON	30	30	Y	M. Electrician	0%	100%	19:00	20:00	1:00
3	CMT	3	Project Control Lead		X		AB	7	30	Y	Operator - Farming	25%	75%	16:00	17:08	1:08
4	CMT	3	Construction Manager		X		ON	29	29	N	N/A	30%	70%	20:10	20:42	0:32
6	CMT	3	Project Control Lead		X		ON	28	28	N	N/A	10%	90%	10:25	11:22	0:57
7	CMT	2	Safety Lead		X		NL	15	25	Y	Equipment Ops	50%	50%	8:20	9:15	0:55
8	CMT	2	Safety Lead		X		ON	9	19	N	N/A	0%	100%	17:40	18:30	0:50
9	CMT	4	Electrical Lead		X		BC	35	35	Y	M. Electrician	50%	50%	19:00	20:25	1:25
10	CMT	3	Mechanical Lead		X		BC	40	40	Y	Pressure Welder	60%	40%	10:00	11:20	1:20
11	CMT	4	Safety Lead		X		ON	30	45	Y	Electrician	85%	15%	13:15	14:10	0:55
12	CMT	3	Planner		X		BC	20	30	Y	Power Engineer	100%	0%	14:00	15:10	1:10
13	CMT	4	Material Coord.	X			QC	10	40	Y	Trucker	90%	10%	18:30	19:39	1:09
14	CMT	3	Mechanical Lead		X		AB	10	35	Y	Pipefitter	0%	100%	16:30	17:45	1:15
15	CMT	4	Safety Manager		X		SK	45	45	N	N/A	40%	60%	15:45	16:45	1:00
17	Owner	3	Commissioning Mngr		X		FL	30	30	Y	Instrumentation	20%	80%	16:15	17:40	1:25
19	Owner	4	Performance Consult.		X		NC	40	40	Y	Roughnecks	0%	100%	14:00	15:13	1:13
20	Const	2	Senior PM		x		ON	11	18	N	N/A	55%	45%	21:35	22:30	0:55
21	CMT	2	Contract Manager		X		NB	25	25	N	N/A	25%	75%	13:15	14:05	0:50
22	Hyb	3	VP Procurement			X	Lyon	12	35	N	N/A	60%	40%	9:00	10:05	1:05
24	Owner	1	VP International Projects		X		Vers	12	12	N	N/A	100%	0%	9:20	10:22	1:02
25	Owner	1	Mechanical Eng - Mngr		X		SK	18	18	N	N/A	20%	80%	16:15	17:30	1:15
26	Owner	2	Mechanical Eng - Mngr		X		SK	17	17	N	N/A	70%	30%	12:15	13:00	0:45
32	Hyb	3	Project Manager	X			QC	35	35	N	N/A	50%	50%	12:50	13:40	0:50
33	Const	2	Contract Manager	X			QC	20	20	N	N/A	50%	50%	12:35	13:28	0:53
42	Const	2	Project Manager		X		QC	22	22	N	N/A	75%	25%	18:30	19:24	0:54
47	Hyb	4	Logistics Manager	X			QC	30	40	N	N/A	100%	0%	9:45	11:00	1:15
50	Owner	3	Senior Project Scheduler		X		SK	20	22	Y	Electrician	50%	50%	17:30	18:20	0:50
51	Hyb	3	Project Manager	X			QC	28	28	N	N/A	50%	50%	15:50	17:10	1:20
		28		5	22	1		648	813	13						28:58:00
High		3						40	45							0:32:00
Low		2						7	12							1:25:00
Mean		47.86		18%	79%	4%		23.14	29.04			46%	54%			1:02:04
Owner		6	21%													
Construction		3	11%													
Hybrid		4	14%													
CMT		15	54%													
Age Groupe 1 (30-39)		2	7%													
Age Groupe 2 (40-49)		8	29%													
Age Groupe 3 (50-59)		12	43%													
Age Groupe 4 (60+)		6	21%													

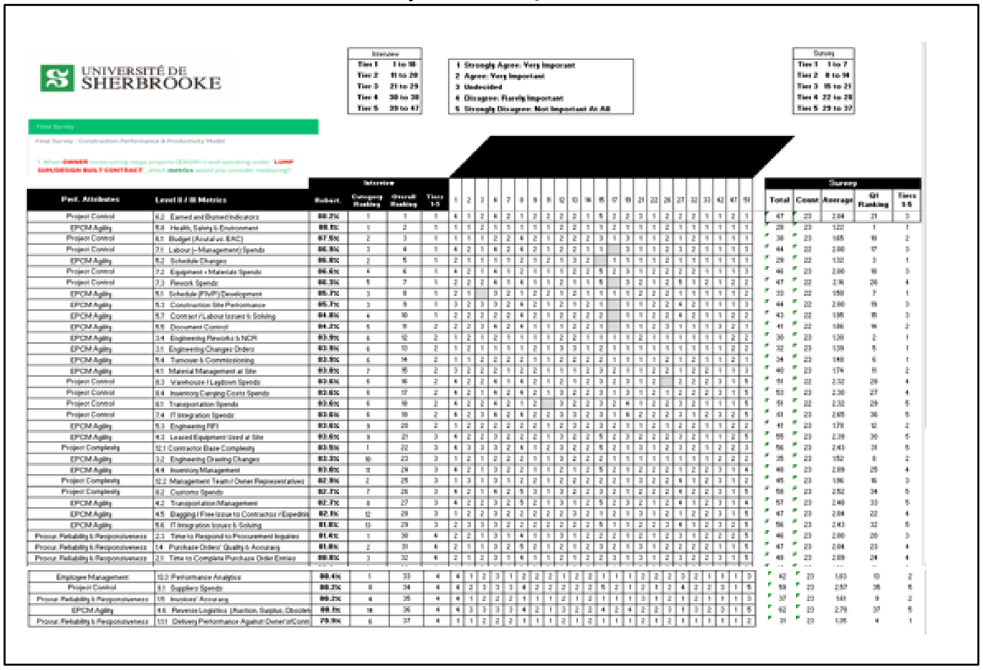
Dany Julien (2019)

APPENDIX K

SURVEY'S RESULTS

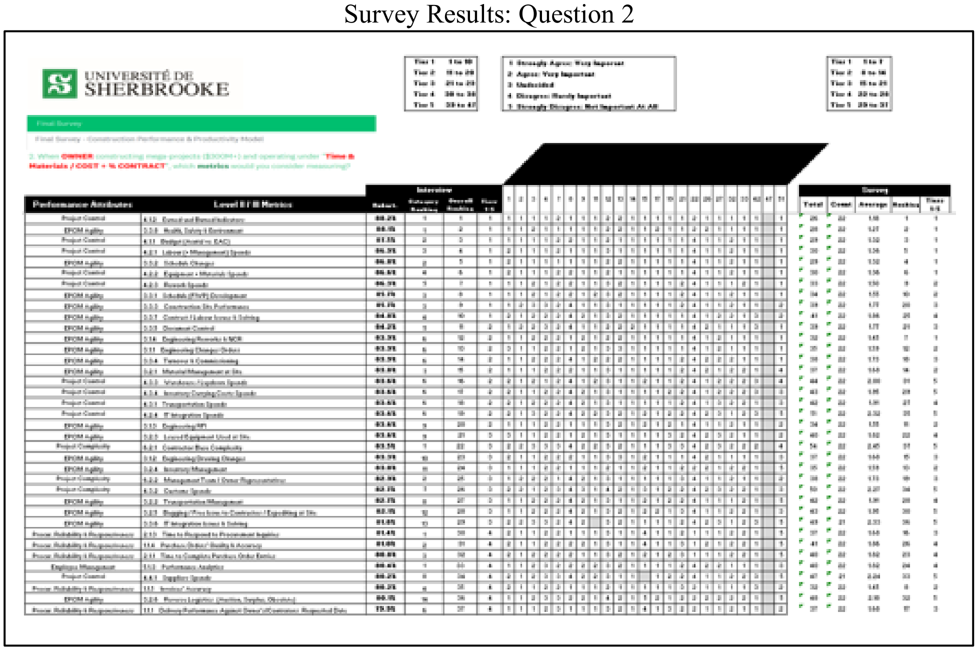
SURVEY'S RESULTS

Table K. 1 Survey Results: Question 1
Survey Results: Question 1



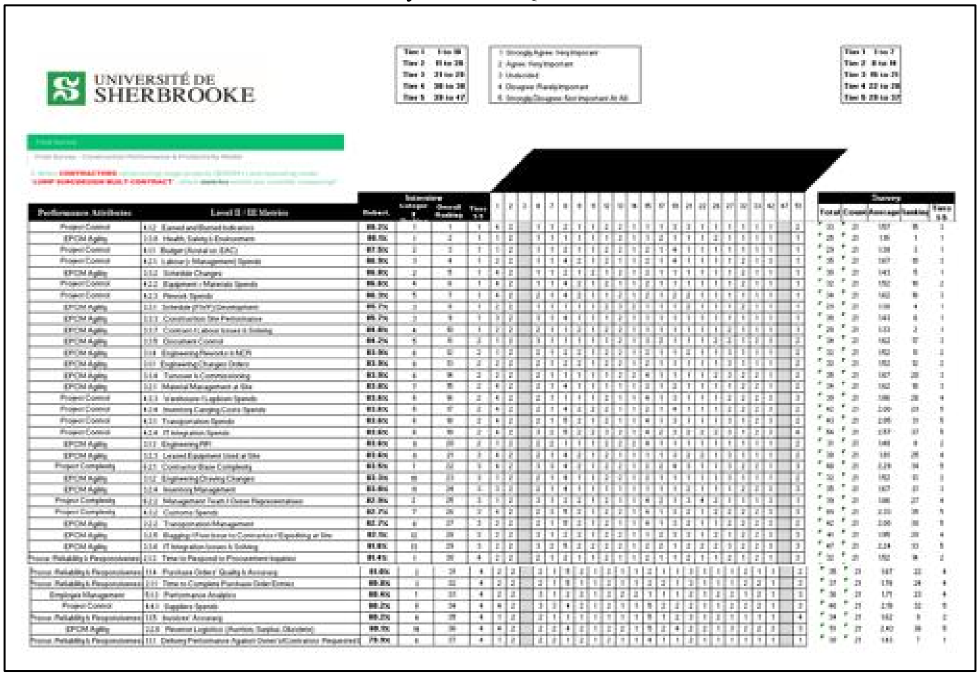
Dany Julien (2019)

Table K. 2 Survey Results: Question 2
Survey Results: Question 2



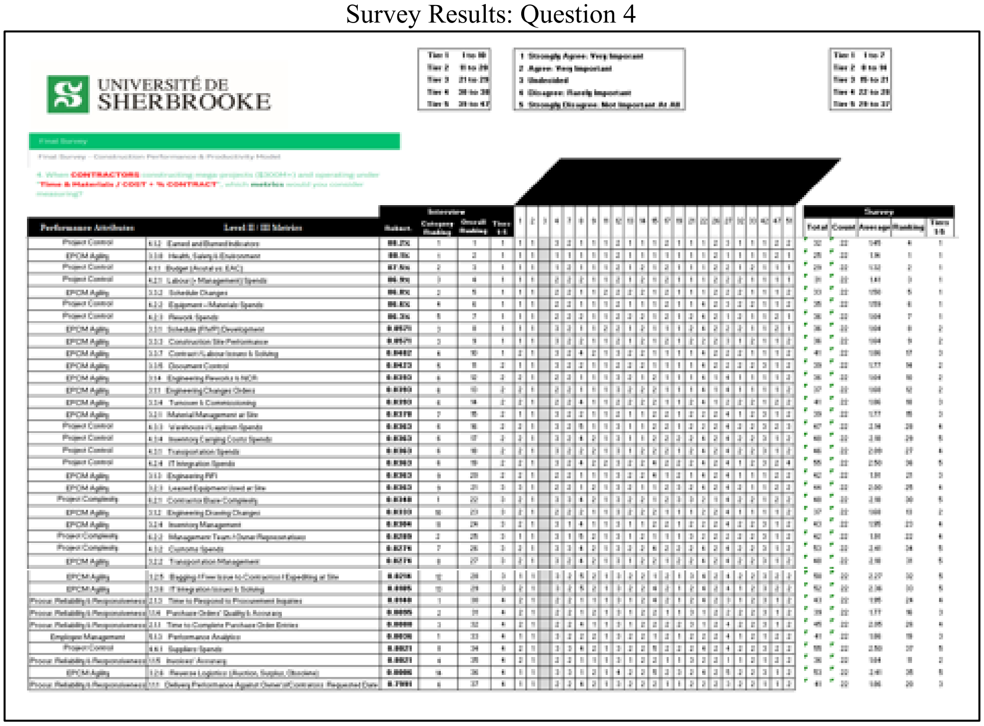
Dany Julien (2019)

Table K. 3 Survey Results: Question 3
Survey Results: Question 3



Dany Julien (2019)

Table K. 4 Survey Results: Question 4
Survey Results: Question 4



Dany Julien (2019)

APPENDIX L1

PROCUREMENT RELIABILITY: LEVEL III

PROCUREMENT RELIABILITY: LEVEL III METRICS

Table L1. 1
Level III: Schedule PO

<table>
<tr><th colspan="2">PROCUREMENT RELIABILITY
(I)</th><th>Level I Metric

1. Delivery Performance</th></tr>
<tr><td colspan="2">Level II Metrics</td><td>Level III Metrics</td></tr>
<tr><td>1.1</td><td>Scheduled Purchase Orders Made by Owner's Request</td><td><u>Number of Purchase Orders Transmitted</u>
Total number of purchase orders transmitted to suppliers by the owner. The unit of measurement is numerical.
<u>per Week / Month / per Year (1.1.1; 1.1.2; 1.1.3)</u>
Total number of purchase orders transmitted by the owner to its suppliers per week / month / year. The unit of measurement is “numerical”.
<u>per Area (1.1.4)</u>
Total number of purchase order that are transmitted by the owner to suppliers per specific area of construction. The unit of measurement is “numerical”.
<u>Number of Purchase Orders Delivered</u>
Total number of purchase orders executed by the owner. The unit of measurement is numerical.
<u>per Week / Month / per Year (1.1.5; 1.1.6; 1.1.7)</u>
Total number of purchase orders delivered to owner’s warehouse or laydown per week / month / year. The unit of measurement is “numerical”.
<u>per Area (1.1.8)</u>
Total number of purchase order that are delivered at site per specific area of construction. The unit of measurement is “numerical”.
<u>Number of Short Notice Purchase Orders (1.1.9)</u>
This metric measures the number of purchase order made and to be delivered within one (1) week. The unit of measurement is “numerical”.

<u>Percentage (%) of Short Notice Purchase Orders (1.1.10)</u>
This metric measures the percent (%) number of purchase order made and to be delivered within one (1) week. The unit of measurement is “numerical (%)”.</td></tr>
</table>

Dany Julien (2019)

Table L1. 2
Level III: Delivery Performance on Owners' Date

PROCUREMENT RELIABILITY (I)		Level I Metric 1. Delivery Performance
Level II Metrics		Level III Metrics
1.2	Delivery Performance Against Owner's Purchase Orders Requested Date	<u>Number of PO Delivered On Time to Owner's Request Date (**1.2.1**)</u> Total number of purchase orders delivered on-time to owner, as per owner's request date. The unit of measurement is "numerical". • <u>Total Number of POs Delivered In Full to Owner's Request Date (**1.2.2**)</u> Total number of purchase orders delivered in-full to owner, as per owner's request date. The unit of measurement is "numerical". • <u>Total Number of PO Delivered On Time and In Full to Owner's Request Date (**1.2.3**)</u> Total number of purchase orders delivered on-time and in-full to owner, as per owner's request date. The unit of measurement is "numerical". <u>Number of Open PO, yet to be received (**1.2.4**)</u> Total Number of purchase order that have been authorized, but yet to be received. The unit of measurement is "numerical". <u>Percentage (%) of PO Delivered to Owner's Request Date (**1.2.5**)</u> The percentage of orders that are fulfilled by the supplier on or before the original requested delivery date. The intent of this measure, the frequency with which suppliers meet the owner's requested date. The unit of measurement is "numerical (%,)" you wish to maximize it. <u>Variance On Time Delivery – Request Date (**1.2.6**)</u> Variance is obtained from comparing data each month – percent (%) of PO Delivered to Owner's Request Date. The unit is "numerical" and you target minimum variance (near "0").

Dany Julien (2019)

Table L1. 3
Level III: Delivery Performance Suppliers Date

PROCUREMENT RELIABILITY (I)		Level I Metric 1. Delivery Performance
Level II Metrics		**Level III Metrics**
1.3	Delivery Performance of Purchase Orders Against Suppliers' Committed Date	Number of Orders Delivered On-Time by Supplier's Committed Date (**1.3.1**) Total number of purchase orders delivered on-time by Supplier's Committed Date. The unit of measurement is "numerical". • Number of Orders Delivered In Full by Supplier's Committed Date (**1.3.2**) Total number of purchase orders delivered in-full by Supplier's Committed Date. The unit of measurement is "numerical". • Number of Orders Delivered On-Time and In Full to Supplier's Committed Date (**1.3.3**) Total number of purchase orders delivered on-time and in-full by Supplier's Committed Date. The unit of measurement is "numerical". Percentage (%) of Orders Delivered by Supplier's Committed Date (**1.3.4**) The percentage of orders that are fulfilled by the supplier on or before the original committed delivery date. The intent is to monitor and improve the percent of supplier items are delivered complete (correct quantity), on time, and of acceptable quality, based upon supplier schedules and agreed to delivery dates for non-supplier scheduled items. The unit of measurement is "numerical (%)" and must be maximised. Frequency of Supplier Performance Analysis (**1.3.5**) Time period within which analysis of the supplier performance is redone. May vary by supplier and commodity category. The unit of measurement should be "quarterly, mid-year or yearly".

Dany Julien (2019)

Table L1. 4
Level III: Perfect PO Fulfillment

PROCUREMENT RELIABILITY (I)		Level I Metric 1. Delivery Performance
Level II Metrics		**Level III Metrics**
1.4	Perfect Purchase Orders' Fulfillment	Number of Orders Delivered In Full (1.4.1) Total number of purchase orders delivered on-time and in-full – in accordance with owners request date and suppliers' committed date. The unit of measurement is "numerical". Percentage (%) of Orders Delivered In Full (1.4.2) Percentage of orders which all of the items are received by customer in the quantities committed. The error-free rate of each stage of an order. Error rates are captured at each stage (order entry, picking, and delivery, shipped without damage, invoiced correctly) and multiplied together. The unit of measurement is "numerical (%)" and must be maximised.

Dany Julien (2019)

Table L1. 5
Level III: PO Quality & Accuracy

PROCUREMENT RELIABILITY (I)		**Level I Metric** **1. Delivery Performance**
Level II Metrics		**Level III Metrics**
1.5	**Purchase Orders' Quality & Accuracy**	Number of Change Request made to Purchase Order (**1.5.1**) Total number of changes that are made after purchase orders are written. The unit of measurement is "numerical" and must be minimised. Number of Cancelled Purchase Order (**1.5.2**) Number of time that cancelations are made to purchase orders already written. The unit of measurement is "numerical" and must be minimised. Number of Damage per Total Number of Purchase Orders transmitted (**1.5.3**) Number of purchase orders that are damage materials or equipment delivered at owner warehouse or construction site as per purchase order. The unit of measurement is "numerical" and must be minimised Percentage (%) of Damage per Total Number of Purchase Orders Transmitted (**1.5.4**) Percentage of purchase orders that are damage materials or equipment delivered at owner warehouse or construction site as per purchase order. The unit of measurement is "numerical (%)" and must be minimised. Percentage (%) Accuracy of Bill of Materials (**1.6.1**) This metric ensures that all bills of material accurately state the component materials, including the quantities and units of measure. The unit of measurement is % and must be maximised. Percentage (%) Order Shortages on Invoice (**1.5.5**) The number of items ordered compared with items shipped. Fill rate can be calculated on a line item, SKU, case or value basis. Accuracy (%) + Shortage (%) = 100% BOM. The unit of measurement is "numerical (%)" and must be minimised. Percentage (%) Accuracy of Bill of Materials by Trades (**1.5.6**) This metric measures the different BOM's accuracy by Trades such as mechanical suppliers, electrical suppliers, etc. The unit of measurement is "numerical (%)" and must be maximised. Purchase Order Approval Ratio (**1.5.7**) This metric measures the number of purchase orders that are rejected divided by total number of purchase orders that have been approved. The unit of measurement is "numerical (%)" and must be maximised.

Dany Julien (2019)

Table L1. 6
Level III: Invoices' Accuracy

PROCUREMENT RELIABILITY (I)		**Level I Metric** **1. Delivery Performance**
Level II Metrics		**Level III Metrics**
1.6	**Invoices' Accuracy**	Accuracy • Invoice Accuracy, Suppliers, Contractors, Carriers (**1.6.1; 1.6.2; 1.6.3**) This metric measure the contractors' invoice accuracies. This metric track and improve billing accuracy by discovering and eliminating root causes of billing errors. The unit of measurement is "numerical" and must be maximised. On-Time • Percentage (%) of Invoices submitted On Time (**1.6.4**) The percentage (%) of invoice submitted within 30 days (PO terms) after completing their activities. The unit of measurement is "numerical (%)" and must be maximised. Data Input Efficiencies • Number of Invoices / Suppliers / Carriers / Contractors (**1.6.5; 1.6.6; 1.6.7**) Total number of invoices submitted to owner, sent by suppliers, carriers, contractors. The unit of measurement is "numerical". • Percentage (%) of Manual Input Invoices (**1.6.8**) Percent of invoices manually input by hand (e.g. Site staff not having access to ERP system). The unit of measurement is "numerical (%)" and must be maximised. • Percentage (%) of Automatic Invoice (**1.6.9**) This metric measures the percentage (%) of automated invoices that are processed via Automation/Total Invoices Processed. The unit of measurement is "numerical (%)". Blocked Invoices • Number of Formal Disputes / On Hold / Blocked Invoices (**1.6.10**) This metrics measures the total number of invoices that are in disputes, or on-hold or blocked. The unit of measurement is "numerical" and should be minimised.

Dany Julien (2019)

APPENDIX L2

PROCUREMENT RESPONSIVENESS: LEVEL III

PROCUREMENT RESPONSIVENESS: LEVEL III METRICS

Table L2. 1
Level III: PO Entry Completed

PROCUREMENT RESPONSIVENESS (II)		**Level I Metrics** **2. Purchase Order (PO) Fulfillment Cycle Time**
Level II Metrics		**Level III Metrics**
2.1	**Purchase Order Entry Completed** **(Time)**	Average Time to Issue Purchase Order – Owner/EP/CM (**2.1.1; 2.1.2; 2.1.3**) Average time it takes to issue a Purchase Order, once the Purchase Request is made. Time to issue PO is measured against Owner, Engineering firm and Contractors. The unit of measurement is "time" and should be minimized. Material Source Identification Cycle (**2.1.4**) Total cycle time from the time a material requirement is identified by Engineering and until selecting supplier capable of fulfilling that requirement are identified by Procurement. The unit of measurement is "time" and should be minimized. RFQ - Source Selection Cycle (**2.1.5**) Total elapsed time from the time the RFQ is sent to bidders until the contract is awarded by Procurement and accepted by the Supplier. The unit of measurement is "time" and should be minimized.

Dany Julien (2019)

Table L2. 2
Level III: Invoice Received at Owner

PROCUREMENT RESPONSIVENESS (II)		**Level I Metrics** **2. Purchase Order (PO) Fulfillment Cycle Time**
Level II Metrics		**Level III Metrics**
2.2	**Invoice Received at Owner** **(Time)**	Cycle Time, Receipt of Invoice - Suppliers / Carriers (**2.2.1; 2.2.2**) The time is take to receive an invoice from a supplier / carrier after receiving the materials/equipment at owner's warehouse or site laydown. The unit of measurement is "time" and should be minimized. Cycle Time, Receipt of Invoice - Contractors (**2.2.3**) The time is take to receive an invoice from a contractor after receiving approval for Rules of Credits. The unit of measurement is "time" and should be minimized. Cycle Time, Process Invoice Payment (**2.2.4**) The time is take the owner to process and invoice payment. The unit of measurement is "time" and should be minimized.

Dany Julien (2019)

Table L2. 3
Level III: Inquiry Time – Procurement

PROCUREMENT RESPONSIVENESS (II)		**Level I Metrics** **2. Purchase Order (PO) Fulfillment Cycle Time**
Level II Metrics		**Level III Metrics**
2.3	**Inquiry Time – Procurement** **(Time)**	Average Time - Carrier Quote Response (**2.3.1**) The time it take for a carrier to respond to owner's request or answer a tender. The unit of measurement is "time" and should be minimised. Average Time – Supplier Quote Response (**2.3.2**) The time it take for a supplier to respond to owner's request or answer a tender. The unit of measurement is "time" and should be minimised.

Dany Julien (2019)

APPENDIX L3

EPCM AGILITY: LEVEL III

EPCM AGILITY: LEVEL III METRICS

Table L3. 1
Engineering Changes

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
3.1	Engineering Changes	Number of Change Orders / Deviation Changes (3.1.1) Total number of implemented changes ordered since the beginning of the project. The unit measurement is "numerical" and must be minimised. • Number of Change Orders – per week / month / Area (3.1.2; 3.1.3; 3.1.4) Total number of implemented changes ordered for the week, the month. A high number of change for a specific area may indicate a weakness in the engineering group in charge of that area. The unit measurement is "numerical" and must be minimised. Average Time to Respond to an Engineering Changes / Change Order / Deviation Order (3.1.5) Average time to respond to an engineering change or change order or deviation order made by a manufacturer or contractor. The lower the number, the more responsive a firm is in implementing engineering changes. The unit measurement is "time" and must be minimised. Engineering Change Order Impact on Delay (3.1.6) Total number of days each engineering change impacts on the delivery package date (FIWP). The unit measurement is "time" and must be minimised.

Dany Julien (2019)

Table L3. 2
Engineering Drawings

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
3.2	**Engineering Drawings**	Number of Drawings Released (**3.2.1**) Number of released drawings are designed and released for construction. The unit of measurement is "numerical" and must be maximised. Data Accuracy for Drawings (**3.2.2**) The ratio indicating the relative measure of data accuracy for all drawings. Formula will measure total number of drawings minus the number of error over the total number of drawings. The unit of measurement is "numerical (%)" and must be maximised. Data Rejection for Drawings (**3.2.3**) The total number of drawings that were rejected due to duplication or cancelation (change in design). The unit of measurement is "numerical" and must be minimised. Drawing Effort (**3.2.4**) Average number of engineering man-hours-months for each drawing released to construction. This ratio shows the resources required to produce a design. The unit of measurement is "time".

Dany Julien (2019)

Table L3. 3
Engineering RFI

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
3.3	Engineering RFI	Number of RFI – Suppliers / Manufacturers (**3.3.1**) Total number of RFI requested by suppliers or manufacturers. The unit of measurement is "numerical" and must be minimised. Number of RFI – All trades/Specific Trades (**3.3.2**) Total number of RFI that are related to all trades-inclusive or specific trade. The unit of measurement is "numerical" and must be minimised. Number of RFI – per Area (**3.3.3**) Total number of RFI that have been submitted and are related to a specific area of construction. The unit of measurement is "numerical" and must be minimised. Average Time to Respond to an RFI – Suppliers/Manufacturers (**3.3.4**) Average time it takes engineering into responding to RFI pertaining to suppliers or manufacturers. The unit of measurement is time and must be minimised. Average Time to Respond to an RFI - All Trades/Specific Trades (**3.3.5**) Average time it takes engineering into responding to RFI. That falls into the category all trades-inclusive or specific to a trade. The unit measurement is time and must be minimised. Number of Outstanding / Opened RFI – Suppliers/Manufacturers (**3.3.6; 3.3.7**) Total number of outstanding / closed RFI requested by suppliers or manufacturers. The unit of measurement is "numerical" and must be minimised. Number of Outstanding / Opened RFI – All Trades/Specific Trades (**3.3.8; 3.3.9**) Total number of outstanding / Opened RFI requested by all trades-inclusive or specific trade. The unit of measurement is "numerical" and must be minimised.

Dany Julien (2019)

Table L3. 4
Engineering Reworks

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
3.4	**Engineering Reworks**	Number of Rework Hours (**3.4.1**) The total number of hours that crews have to work due to all reworks. The unit of measurement is "numerical" and must be minimised. Number of Rework hours – due to Manufacturing (Equipment, Material) Issues (**3.4.2**) The total number of hours that crews have to rework caused by manufacturing defects, equipment defects or material issues. The unit of measurement is "numerical" and must be minimised. Number of Rework Hours – due to Engineering Issues (**3.4.3**) The total number of hours that crews have to rework caused by engineering issues. The unit of measurement is "numerical" and must be minimised. Number of Rework Hours – due to Quality / Contractors (**3.4.4**) The total number of hours that crews have to rework caused by quality issues from the Contractors, mostly during turn over. The unit of measurement is "numerical" and must be minimised.

Dany Julien (2019)

Table L3. 5
Quality NCR

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
3.5	**Quality - NCR**	Number of Non-Conformities Reports – NCR **(3.5.1)** Total number of Non-Conformities Reports. The unit of measurement is "numerical" and must be minimised. • Number of NCR per week, per month, per Area **(3.5.2; 3.5.3; 3.5.4)** This metrics measures the amount of NCR issues each week, each month, or per Area of construction. • Number of Closed NCR **(3.5.5)** This metrics measures the number of Closed NCR; that is NCR than have been resolved. The unit of measurement is "numerical" and must be maximised. • Number of Opened NCR **(3.5.6)** This metrics measures the number of Opened NCR; that is NCR than are still under investigation by engineering or suppliers. The unit of measurement is "numerical" and must be minimised. • Average Cycle Time to Closed NCR **(3.5.7)** This metrics measure the average time (days) it takes Engineering to resolved/closed a NCR. The unit of measurement is "time" and must be minimised. Number of Punches (Deviations / Defects / Deficiencies) by Area **(3.5.8)** This metrics measures the total number of Punches by Area. The unit of measurement is "numerical" and must be minimised. • Number of Opened Punches (Deviations / Defects / Deficiencies) by Area **(3.5.9)** Total number of Punches that remain opened in each Area of construction. The unit of measurement is "numerical" and must be minimised. • Number of Closed Punches (Deviations / Defects / Deficiencies) by Area **(3.5.10)** Total number of Punches that remain opened in each Area of construction. The unit of measurement is "numerical" and must be maximised. Percentage (%) of Punches (Deviations / Defects / Deficiencies) vs FWIP by Area **(3.5.11)** This KPI shows the number of defects recorded in the commissioning / start-up in respect of the system. The number of defects is counted in relation to the number of defective construction parts against total FIWP that are closed. The unit of measurement is "numerical" and must be minimised.

3.5	**Quality - NCR**	• Number of Punches (Deviations / Defects / Deficiencies) due to Suppliers' Materials / Equipment (**3.5.12**) This metrics measures the number of Punches and found to be the responsibilities of the Suppliers' Materials or Equipment. The unit of measurement is "numerical" and must be minimised. • Number of Punches (Deviations / Defects / Deficiencies) due to Contractors' Quality of Work (**3.5.13**) This metrics measures the number of Punches and found to be the responsibilities of the Suppliers' Materials or Equipment. The unit of measurement is "numerical" and must be minimised. • Number of Punches (Deviations / Defects / Deficiencies) due to Engineering Concepts / Designs (**3.5.14**) This metrics measures the number of Punches and found to be the responsibilities of the Engineering Concept or Design. The unit of measurement is "numerical" and must be minimised. • Percentage (%) of Category Punches (**3.5.15**) This metrics measures the percentage of Punches that are categorized and under the responsibility of the Project's Suppliers, Contractors or Engineering departments. The unit of measurement is "numerical (%)" and comparative. Deviations / Defects / Rework Hours • Number of Rework Hours – Punches (Deviations / Defects / Deficiencies) (**3.5.16**) This metrics measures the amount of Extra Rework Hours allocated to complete defective works by Contractors. The baselines for Extra Rework Hours is based on the Actual FIWP Hours for a construction-completed package. The unit of measurement is "numerical" and must be minimised. • Percentage (%) of Rework Hours vs Actual FIWP Hours (**3.5.17**) This metrics divides the amount of Rework Hours over the Actual FIWP Hours for a construction-completed package. This unit is calculated for individual FIWP. The unit of measurement is "numerical (%)" and must be minimised for each FIWP. • Corrective Actions Right First Time (**3.5.18**) This metrics measures the percentage (%) of the ratio of corrective actions done right the first time over total corrective actions. The unit of measurement is "numerical" and must be minimised.

Dany Julien (2019)

Table L3. 6
Material Management

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
4.1	Material Management	Number of Material Receiving Report – MRR (**4.1.1; 4.1.2; 4.1.3; 4.1.4**) This metrics measures the total number of Material Receive Report (MRR) that are received each shipment. The unit of measurement is "numerical" and comparative. • Per week, per month, per year, per Area The MRR can be accounted per Week, per Month, per Year, per Area. The unit of measurement is "numerical" and comparative. Number of Free Issue Material Report – FIMR (**4.1.5; 4.1.6; 4.1.7; 4.1.8**) This metrics measures the total number of Free Issue Material Report (FIMR) that are issued from Owner/CMT to Contractor. The unit of measurement is "numerical" and comparative. • Per week, per month, per year, per Area The FIMR can be accounted per Week, per Month, per Year, per Area. The unit of measurement is "numerical" and comparative. Number of OSD Reports (Over, Short, Damaged Goods) (**4.1.9; 4.1.10; 4.1.11; 4.1.12**) This metrics simply accounts for the number of OSD Reports that have been recorded. The unit of measurement is "numerical" and must be minimised. • Per week, per month, per year, per Area The OSD can be accounted per Week, per Month, per Year, per Area. The unit of measurement is "numerical" and comparative. Number of Tagged Equipment for the Project (**4.1.13**) This metrics measures the total number of tagged equipment for the Project. The unit of measurement is "numerical". • Number of Tagged Equipment Count per Area (**4.1.14**) This metrics measures the total number of tagged equipment for all FIWP pertaining to a specific Area. This metrics provides an appreciation for the size of area to build. The unit of measurement is "numerical". • Number of Tagged Equipment Delivered in full to Site (**4.1.15**) This metrics measures the total number of tagged equipment that have been delivered in full to site. The unit of measurement is "numerical" and must be optimal.

4.1	Material Management	• Percentage (%) of Tagged Equipment Delivered in Full to Site (**4.1.16**) This metrics measures the percentage (%) of tagged equipment delivered in full to site). The unit of measurement is "numerical" and must be maximised. • Number of Tagged Equipment – OSD Reports (**4.1.17**) This metrics measures the number of tagged equipment that were received over/short in count, or damaged goods at job site and enter under an OSD Report. The unit of measurement is "numerical" and must be minimised. Number of Tagged Equipment Issued to Contractors – Area (**4.1.18**) This metrics measure the number of Tagged Equipment that have been issued to the Contractors for a specific Area of construction. The unit of measurement is "numerical" and must be maximised. Percentage (%) of Tagged Equipment Issued to Contractors - Area (**4.1.19**) The percentage (%) of Tagged Equipment Count Issued to Contractors per Area / per Project is used to measure the percentage of tag equipment issued versus the Contractor percentage progress report. In practical, a project cannot have higher progress than tag equipment issued. The unit of measurement is "numerical (%) and must be maximised.

Dany Julien (2019)

Table L3. 7
Transportation Management

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
4.2	**Transportation Management**	Percentage (%) of On-Time Arrival – Carrier (**4.2.1**) This metric measures the percentage (%) of on-time arrival achieved by all carriers. The unit of measurement is "numerical (%)" and must be maximised. Number of Late ETAs - All Carriers (**4.2.2**) This metric accounts for the total number of Late ETAs by all Carriers, which is measured against carrier's forecasted ETAs. The standard is +/- 2 hours per ETA forecast. The unit of measurement is "numerical" and must be minimised Average Time – Late ETAs for Specific Carrier (**4.2.3**) Measured the carrier average mean time for late ETA for Specific Carrier. The unit of measurement is "time" and must be minimised. Average Transit Time between Owner's / EPC Warehouse and Site Laydown (**4.2.4**) Measured by the number of hours or days from the time a shipment leaves the Owner's warehouse to the time it arrives at a construction site laydown. The unit of measurement is "time" and must be minimised. Average Time - Customs Clearance (**4.2.5**) The average time it takes for a freight to clear customs. The unit of measurement is "time" and must be minimised. Quantity (kg) per shipment/delivery (**4.2.6**) This metric measures the average quantity (kg) per shipment based on each delivery (MRR). The unit of measurement is weight and must be maximised.

Dany Julien (2019)

Table L3. 8
Leased Equipment Availability

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
4.3	**Leased Equipment Availability**	Number of Leased Equipment at job site (**4.3.1**) This metrics measures the total number of leased equipment at job site. The unit of measurement is "numerical" and must be minimised. Number Equipment per Area / per Trade (**4.3.2**) This metrics measures the total number of leased equipment per Area or per Trade at job site. The unit of measurement is "numerical" and must be minimised. Percentage (%) of Equipment availability (**4.3.3**) This metric measures the equipment availability or its use in respect to its Operating Time divided by 24 hours/day or the total amount of hours when totaling all shift. The unit of measurement is "numerical (%)" and must be maximised.

Dany Julien (2019)

Table L3. 9
Inventory Management

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
4.4	**Inventory Management**	Total Distribution Floor Space (**4.4.1**) This metric measure the percentage (%) space taken by materials/equipment. The unit of measurement is "numerical (%)" and must be maximised. Inventory Record Accuracy (**4.4.2**) Define the distribution network by identifying all inventory stocking locations, the supply sources, which products are stocked in each, what modes of transport are employed to replenish the stocking locations, shipping frequency, lead times, lot sizes and any other attributes which may be required by the integrated planning software being employed. All tagged materials are counted at a minimum of once per month. All bulk materials are accounted bi-monthly. Inventory accuracy can be segregated by trades The unit of measurement is "numerical, percentage (%) and monetary". These metrics must be optimal. Inventory, Receiving Cycle – from warehouse / laydown to Installation (**4.4.3**) The average time required to move inventory from internal storage to ready-for-field installation. The unit of measurement is "time" and must be minimised. Manual Input Ratio – inventories (**4.4.4**) This metric calculated the percentage (%) of manual inventories input, when an automated system is available. The unit of measurement is "numerical (%)" and must be minimised. Percentage (%) of Surplus to Inventory (**4.4.5**) The ratio indicating the relative measure of the currently surplus or inactive assets held against the Total Inventory. The unit of measurement is numerical (%) and must be minimised.

Dany Julien (2019)

Table L3. 10
Bagging / Expediting at Site

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
4.5	Bagging / Expediting at Site	Number of Tagged Equipment/Materials per FIWP (**4.5.1**) This metric measures the total number of Tagged equipment/materials, cumulative for each FIWP. The unit of measurement is "numerical". Percentage (%) of Tagged Equipment/Materials Transferred per FIWP (**4.5.2**) This metric measures the percentage (%) of Tagged equipment/materials that have been expedited from warehouse / Laydown for each FIWP. The unit of measurement is "numerical (%)" and must increase during the duration of the projet. Number of Picking Error During Bagging (**4.5.3**) This metric measures the total number of bagging error during bagging (expediting) activities. Percentage (%) of Picking Error During Bagging (**4.5.4**) This metric measures the total number of picking errors when expediting / bagging tagged equipment / materials to crews in field, ready for installation. The unit of measurement is percentage (%) and must be minimised.

Dany Julien (2019)

Table L3. 11
Reverse Logistics

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
4.6	Reverse Logistics	Number of Materials/Equipment classified as Waste Recycled (**4.6.1**) Number of materials/equipment that has become obsolete to the project, and has been classified as waste recycled, The unit of measurement is "numerical" (length, unit, size, etc.) and must be minimised. Mean Time to Repair (MTTR1) (**4.6.2**) Average time between the occurrence of a defect and its resolution (being repaired). The unit of measurement is "time" and must be minimised. Mean Time to Replaced (MTRR2) (**4.6.3**) Average time it take foe equipment/material to return off-on site at 100% value, fully repair. The unit of measurement is "time" and must be minimised.

Dany Julien (2019)

Table L3. 12
Scheduled Development

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
5.1	Schedule (FIWP) Development	Design Development Schedule Adherence (Level II, III, IV, V) (**5.1.1**) This metrics (number of days) measures the adherence in meeting schedule development at each level. This measure indicate poor execution if late in execution. The unit of measurement is "time" and must be minimised. FIWP Drawings and build hours per square meter (**5.1.2**) This KPI shows the required man hours of drawing for an FIWP, in compare to the built up area of the project. It is going to be changed according to the project type but it gives a role of thumb to estimate the required man hour for the design and production of tender documents drawings. The unit of measurement is "time". Number of FIWP Package for the Project (**5.1.3**) This metrics measures the total number of FIWP Package for the project. The unit of measurement is "numerical". • Number of FIWP Packages per Trade (**5.1.4**) • Number of FIWP Packages per Area (**5.1.5**) • Number of FIWP Packages per Trade/Area (**5.1.6**) Number of FIWP Completed at the start of Construction (**5.1.7**) This metric measure the amount of FIWP completed and approved, at the start of the project. The unit of measurement is "numerical" and must be maximised. Percentage (%) of FIWP Completed at the start of Construction (**5.1.8**) This metric measure the percentage (%) of FIWP completed and approved, at the start of the project. A target percentage for this KPI is 0.60. The unit of measurement is "numerical (%)" and must be maximised. Number of Planned Hours – All FIWP for the Project (**5.1.9**) This metrics sums up the total number of planned hours for completing all FIWP for the Project. The unit of measurement is "time". Average Number of Planned Hours per FIWP (**5.1.10**) The average FIWP in a project plan is an item that takes crews approximately 500 to 1000 hours to complete. This metrics measures the average of planned hours per FIWP. The unit of measurement is "time". Number of Milestones for the Project (**5.1.11**) This metrics measures the total number of milestones for the project. The unit of measurement is "numerical". Number of Milestones per Area (**5.1.12**) This metrics measures the total number of milestones in each area of construction. The unit of measurement is "numerical".

Dany Julien (2019)

Table L3. 13
Scheduled Changes

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
5.2	**Schedule Changes**	Number of Schedule Changes (one or many FIWP) – Engineering / Construction **(5.2.1)** This metrics simply measure the amount of schedule changes made by the Schedule Master due to Engineering or Contractors' changes. The unit of measurement is "numerical" and must be minimised. Average Days per Schedule Change (one or many FIWP) **(5.2.2)** The number of average days (Total Number of Change Days divided by Total Number of Schedule Changes). The unit of measurement is "time" and must be minimised. Number of Schedule Changes (one or many FIWP) – Suppliers Lead Time **(5.2.3)** This metrics simply measure the amount of schedule changes made by the Schedule Master due to Suppliers' late delivery from their Lead Time target. The unit of measurement is "numerical" and must be minimised. Average Days per Schedule Change (one or many FIWP) – Suppliers Lead Time **(5.2.4)** The number of average days (Total Number of Change Days divided by Total Number of Schedule Changes). The unit of measurement is "time" and must be minimised. Number of Change Days for Overall Project **(5.2.5)** Total Number of Changes Days for Overall Project caused by Engineering / Construction and Suppliers' Late deliveries. The unit of measurement is "time" and must be minimised.

Dany Julien (2019)

Table L3. 14
Site Performance

<table>
<tr><th colspan="2">EPCM Agility
(III)</th><th>Level I Metrics

3. "E" – Engineering
4. "P" – Procurement
5. "CM" – Construction Management</th></tr>
<tr><th colspan="2">Level II Metrics</th><th>Level III Metrics</th></tr>
<tr><td>5.3</td><td>Site Performance</td><td>FIWP Review (reference: 5.1.3 to 5.1.8)

• Number of FIWP – Review Completed (5.3.1)
This metrics measures the number of FIWP that have been reviewed by Owner / CMT. Review must executed at job site. The unit of measurement is "numerical" and must be maximised.

• Number of FIWP – Review Not Started (5.3.2)
This metrics measures the number of FIWP that have not been reviewed by Owner / CMT. Review must be executed at job site. The unit of measurement is "numerical" and must be minimised.

• Number of FIWP – Review Ongoing: Need Actions (5.3.3)
This metrics measures the number of FIWP that have been reviewed by Owner / CMT, however, major actions (design changes, RFI, materials ETA, materials substitution, etc.) must be resolved. Review must be executed at job site. The unit of measurement is "numerical" and must be minimised.

FIWP – Quantity (reference: 5.1.3 to 5.1.8)

• Number of FIWP Starting on Time against Planned Released (5.3.4)
This metrics measures the FIWP that are released on time to contractors versus the original planned release date. The unit of measurement is "numerical" and should be maximised.

• Percentage (%) of FIWP Release on Time against Planned Released (5.3.5)
This metrics measures the percentage (%) of FIWP that are released on time to contractors versus the original planned release date. The unit of measurement is "numerical (%)" and should be maximised.

• Number of FIWP Completed (5.3.6)
The total number of FIWP completed for the Project. The unit of measurement is "numerical" and should be maximised.

• Number of FIWP Completed On-Time (5.3.7)
The total number of FIWP completed On-Time for the Project. The unit of measurement is "numerical" and should be maximised.

• Percentage (%) FIWP – Completed On Time / Late (5.3.8)
This metrics measures the percentage (%) of the FIWP that has been completed to date. The unit of measurement is "numerical (%)" and must be maximised.</td></tr>
</table>

5.3	**Site Performance**	• Percentage (%) of FIWP - Opened (FIWP) (**5.3.9**) The metrics measures the percentage (%) of FIWP that are not completed. The unit of measurement is "numerical (%)" and must be minimised. • Canceled / Abandon Program (FIWP) Rate (**5.3.10**) This metrics measures the Total number of Cancelled FIWP. The unit of measurement is "numerical" and must be minimised. FIWP – Time (reference: 5.1.9 to 5.1.10) • Deviation of Planned Hours of Work – Actual Hours of Work (**5.3.11**) This metrics is the difference (+/-) in time between the Planned baselines against the Actual Schedule. High deviation is a sign of overrunning the estimated time schedule, which may imply higher costs and lower ROI. The unit of measurement is "time" and must be minimised for each FIWP. • Number of Deviation Hours per FIWP caused by Engineering / Construction / Suppliers(**5.3.12**) (**5.3.13**) (**5.3.14**) This metrics measures the total number of accumulated deviation hours suffered by each FIWP, which were caused by either Engineering, Construction or Suppliers. The unit of measurement is "time" and must be minimised for each FIWP. • Number of hours (FTE – Full Time Employment) actually working on FIWP that were not initially assigned – Extra Works (**5.3.15**) This metrics measures the total number of hours (FTE – Full Time Employment) actually working on FIWP that were not initially planned at the start of the FIWP. The unit of measurement is "time" and must be minimised for each FIWP. • Percentage (%) (FTE – Full Time Employee) actually working on FIWP that were not initially assigned – Extra Works (**5.3.16**) This metrics measures the percentage (%) of number of hours (FTE – Full Time Employment) actually working on FIWP that were not initially planned at the start of the FIWP against total planned hours. The unit of measurement is "time" and must be minimised for each FIWP. • Finished FIWP cycle time (**5.3.17**) This metrics calculates, once the FIWP construction-completed, the average time associated with finalizing FIWP activities. The unit of measurement is "time" and must be minimised for each FIWP. • Actual Construction Hours vs Planned Construction Hours (**5.3.18**) The actual project construction man hours are recorded and analysed against the original planned (baseline) construction man hours on a monthly basis. Variance could be expressed as a percentage from the baseline. The unit of measurement is "time" and must be minimised for each FIWP. Milestones (reference: 5.1.11 to 5.1.12) • Percentage (%) of Milestones Completed for the Project (**5.1.19**) This metric measures the total percentage (%) of milestones completed for the Project.

5.3	**Site Performance**	• Percentage of Milestone Achievement per Area (**5.3.20**) This metrics measures the percentage (%) of milestone that are completed when compared to total number of milestone per area. The unit of measurement is "numerical (%)" and must be maximised. • Number of Milestones Missed per Area (**5.3.21**) This metrics measures the amount of milestones missed in in each area Number of milestones of project missed. The unit of measurement is "numerical" and must be minimised. Performance Index Schedule Performance Index (SPI) (**5.3.22**) Earned Value (EV) divided by Planned Value. The SPI target is 1. If SPI is less than 1, it indicates that the crews are completing the work at a slower pace than what was planned. They are taking more hours to complete the FIWP. The unit of measurement is "time" and must be at SPI=1. SPI = EV / PV Schedule Variance (SV) (**5.3.23**) Earned Value minus the Planned Value." This unit of measurement is "time" and must be at SV=1. SV = EV – PV Cost Performance Index (CPI) or Performance Factor Indicator (PFI) or Earned vs Burned (**5.3.24**) Earned Value (EV) divide by Burned Value (B/V). This unit of measurement is "time" and the target project is CPI = 1 • CPI=PFI below 1: indicate performance issue as Contractors have burned more hours than what they earned. Owner is paying overtime • CPI=PFI above 1: indicate that a contractor has earned more hours of work, when compare to its Actual Hours. The Contractor is efficient. CPI = EV/BV PFI = Earned Hours / Burned Hours

Dany Julien (2019)

Table L3. 15
Document Control

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
5.5	**Document Control**	Number of Document Submitted by Owner / Engineering / Contractors (**5.5.1**) This metrics measures the total number of document submitted by Owner, Engineering firms, Contractors. The measurement unit is "numerical" and comparative. • Per weekly, monthly, yearly. Number of Document Transmitted by Owner / Engineering / Contractors (**5.5.2**) This metrics measures the total number of document transmitted by Owner, Engineering firms, Contractors. The measurement unit is "numerical" and comparative.

Dany Julien (2019)

Table L3. 16
Turnover & Commissioning

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		Level III Metrics
5.4	Turnover & Commissioning	Turnover (T/O) / Commissioning • Number of Turnover (T/O) Document Issued to Owner – Project (**5.4.1**) This metrics measures the total number of T/O Documents that have been issued in the life of the Projet. The unit of measurement is "numerical" and comparative. • Number of Turnover Document Issued to Owner per Area (**5.4.2**) This metrics measures the total number of T/O Documents that have been issued in each Area of construction. The unit of measurement is "numerical" and comparative. • Number of Remediation of Defects After Commissioning / Turnover (**5.4.3**) This metrics measures the total number of defects (extra works or additional services) to be carried out after handing over a system. The unit of measurement is "numerical" and must be minimised. • Number of Turnover (T/O) Document – Opened / Missing Documentation (**5.4.4**) This metrics measures the total number of T/O Documents that have been submitted to the Owner, however, once reviewed, some documents in the package are missing. The unit of measurement is "numerical" and must be minimised. • Percentage (%) of Turnover (T/O) Document – Opened / Missing Documentation (**5.4.5**) This metrics measures the percentage (%) of total number of T/O Documents with missing documentation divided by the total number of T/O Documents that have been submitted to the Owner. The unit of measurement is "numerical (%)" and must be minimised. • Number of Planned Lessons Learnt Session (**5.4.6**) The total number of Planned Lessons Learnt Session equates to the total number of Area of construction. The unit of measurement is "numerical" and comparative • Percentage (%) of Lessons Learnt Sessions per Area (**5.4.7**) This metrics measures the percentage (%) of completed Lessons Learnt Session for the Project. The unit of measurement is "numerical (%)" and must be maximised.

5.4	**Turnover & Commissioning**	Regulatory Compliance • Cycle Time to Receive Regulatory Compliance (**5.4.8**) This metrics measures the total time it takes to receive Regulatory Compliance, once documents have been submitted to proper authority. The unit of measurement is "time (days)" and must be minimised. • Regulatory Change Compliance Cycle (**5.4.9**) This metrics measures, once notified by the authority, the average time needed to comply with changes in regulatory requirements. The unit of measurement is "numerical" and must be minimised.

Dany Julien (2019)

Table L3. 17
IT Issues

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
5.6	**Information Technology Issues**	Number of IT Requests (**5.6.1**) This metrics measures the number of IT request that have been made during the life of the Project. The measurement unit is "numerical" and comparative. Number of IT Requests – Open (**5.6.2**) This metrics measures the number of IT request that have been made and remain Open. The measurement unit is "numerical" and must be minimised. Percentage (%) of IT Requests – Closed (**5.6.3**) This metrics measures the percentage (%) of IT request that have been Closed. The measurement unit is "numerical" and must be maximised. Average - Cycle Repair Time, IT Request (**5.6.4**) This metrics measures the average elapsed cycle time it takes for IT to resolve an issue. The measurement unit is "time" and must be minimised.

Dany Julien (2019)

Table L3. 18
Contract & Labour

EPCM Agility (III)		**Level I Metrics** **3. "E" – Engineering** **4. "P" – Procurement** **5. "CM" – Construction Management**
Level II Metrics		**Level III Metrics**
5.7	**Contract & Labour**	Number of Contract Review Request (**5.7.1**) This metrics measures the total number of request made to review contract terms and conditions, labour, equipment, materials, etc.… The measurement unit is "numerical" and comparative. Contract Update Cycle Time (**5.7.2**) This metrics measures how quickly is a contract updated after a request has been made and change been approved. The measurement unit is "time" and must be minimised. Number of Labour (FTE) at Site (**5.7.3**) This metrics measures the total number of Full-Time Employee (Management + Labour) working at Site. One name equates one Labour. The measurement unit is "numerical" and must be optimal. • Per Trade; Per week, Per Area (**5.7.4; 5.7.5; 5.7.6**) The total number of Labour at site can be accounted by trades, by area, by week, by month. Number of Labour Overtime Hours – Project (**5.7.7**) This metrics measures the total amount of overtime hours that the project has suffered to date. The measurement unit is "numerical" and must be minimised. Number of Labour Overtime Hours - FIWP (**5.7.8**) This metrics measures the total amount of overtime hours for each FIWP. The measurement unit is "numerical" and must be minimised.

Dany Julien (2019)

Table L3. 19
HS&E Performance

EPCM Agility (III)		Level I Metrics 3. "E" – Engineering 4. "P" – Procurement 5. "CM" – Construction Management
Level II Metrics		**Level III Metrics**
5.8	**Health, Safety & Environment Performance**	Number of Health and Safety Incidents This metrics accounts for the total number of H+S Incidents occurring at a job site. The measurement units are "numerical" and must be minimised. These categories include Workers receiving: • First Aid (**5.8.1**) • Medical Aid (**5.8.2**) • Modified Work (**5.8.3**) • Lost Time Injury (LTI) (**5.8.4**) • Near Miss (**5.8.5**) • Number of fatality per year (**5.8.6**) Number of Environmental Incidents This metrics accounts for the total number of Environmental Incidents occurring at a job site. The measurement units are "numerical" and must be minimised. These categories include: • Property Damages (**5.8.7**) • Environmental Infractions (**5.8.8**) Number of Field Duties This metrics the number of managerial / orientation duties executed by the HS&E staff at a job site. The measurement units are "numerical" and must be optimal. These categories include: • Orientations (**5.8.9**) • OHSAS (**5.8.10**) • Fit Test (**5.8.11**) Number of Permits Issued • Hot Work Permits (**5.8.12**) • Confined Space Permits (**5.8.13**) • Excavation Permits (**5.8.14**) • O&G Purging Permits (**5.8.15**) • Safe Work Plan (**5.8.16**) Average Time Needed to Receive Orientation (**5.8.17**) This metrics measures the average time an employee requires to receive orientation at job site. The measurement units are "time (hours)" and must be optimal.

Dany Julien (2019)

APPENDIX L4

PROJECT CONTROLS: LEVEL III

PROJECT CONTROL: LEVEL III METRICS

Table L4. 1
Budget & Planning

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
6.1	Budget & Planning	Actual Cost **(6.1.1)** The total cost actually incurred until a specific point on the timescale in performing the work for a project or a project activity. Budgeted Cost At Completion (BCAC) = PV **(6.1.2)** This is the planned budget ($) that has been allocated for completing the FIWP activities. It is also known as Planned Value (PV) and can be measured at various timeline during a project. This unit of measurement is "monetary ($)" and comparative. Estimate at Completion (EAC) **(6.1.3)** The estimate from the current point I time of how much it will cost to complete the project or a project activity. This metrics is the actual cost of work performed (Burned Value) plus (+) Estimate to Complete (ETC) for all work remaining. This unit of measurement is "monetary ($)" and comparative. $EAC = BV(=AC) + ETC$ Estimate to Complete (ETC) **(6.1.4)** The expected cost, estimated from the CPI, to complete the remaining work for the project of for a project activity. Cost Performance Index (CPI) **(6.1.5)** A measure of cost efficiency of a project calculated by dividing earned value (EV) by actual cost (AC) $CPI = EV / AC$ Planned Labour Budget per FIWP Hours Estimate **(6.1.6)** This metrics account the Net Present Value of the approved project. Values can be broken down into area of construction or FIWP. This unit of measurement is "monetary ($)" and must be minimised. Costs Deviation of the Planned Budget **(6.1.7)** The deviation of the planned budget (cost) is the difference in costs between the planned baselines against the actual budget. (Actual – Planned). High deviation is a sign of overrunning the estimated budget, which may imply higher costs and lower ROI. This unit of measurement is "monetary ($)" and must be minimised. Time Needed to Obtain Additional Capital **(6.1.8)** Amount of time required to achieve a certain substantial improvement concerning capital. This unit of measurement is "monetary ($)" and must be minimised

Dany Julien (2019)

Table L4. 2
Earned & Burned Indicators

PROJECT CONTROLS (IV)		**Level I Metrics** **6. Budget & Planning** **7. LEM Spends** **8. Logistics Spends** **9. Processing Spends**
Level II Metrics		**Level III Metrics**
6.2	**Earned & Burned Indicators**	Earned Value (EV) or Budgeted Cost of Work Performed (BCWP) (**6.2.1**) This is the value of the actually performed work expressed in terms of the approved budget for a project or a project activity for a given time. It is the total Budgeted Cost at Completion of an activity (BCAC) such as FIWP that has been Earned (EV) through a percentage (%) completed work (%C). This unit of measurement is "monetary ($)" and comparative. EV = BCAC x %C Burned Value (BV) = Amount Expended (AE) (**6.2.2**) This is the dollar value that has been spent to date, to achieve the physical percent complete (%C). This unit of measurement is "monetary ($)" and comparative. BV = Actual Hours Spent doing the work Cost Variance (CV) (**6.2.3**) A measure of cost performance obtained by subtracting actual value (AV) from earned value (EV). A positive result indicate good performance, whereas a negative result indicate bad performance. This is the Earned Value minus (-) Actual Cost (Burned Value). This unit of measurement is "monetary ($)" and comparative. CV = EV – BV

Dany Julien (2019)

Table L4. 3
Labour & Management Spends

PROJECT CONTROLS (IV)		Level I Metrics **6. Budget & Planning** **7. LEM Spends** **8. Logistics Spends** **9. Processing Spends**
Level II Metrics		**Level III Metrics**
7.1	**Labor & Management Spends**	Spend Labor Cost – All Trades (**7.1.1**) This metrics measures the sum of costs associated with payment of Trades' Labor Costs as charged by the Contractors. The unit of measurement is "monetary ($)" and must be minimised. Spend Labor Cost – Management Staffs (**7.1.2**) This metrics measures the sum of costs associated with payment of Management Staffs as charges by Consultants and Contractors. The unit of measurement is "monetary ($)" and must be minimised. Management to Labor Costs Ratio (**7.1.3**) This metrics measures the ratio of Labor costs to Management costs. The unit of measurement is "numerical (%)" and is comparative. Values ($) of Labour Invoices - On Hold or Blocked (**7.1.4**) Total value of On-Hold Invoices or Blocked Invoices that have been submitted under Labour Category. The unit of measurement is "monetary" and must be minimised.

Dany Julien (2019)

Table L4. 4
Materials / Equipment Spends

PROJECT CONTROLS (IV)		**Level I Metrics** **6. Budget & Planning** **7. LEM Spends** **8. Logistics Spends** **9. Processing Spends**
Level II Metrics		**Level III Metrics**
7.2	**Material / Equipment Spends**	Total Spend – Equipment (**7.2.1**) This metrics measures the sum of costs associated with acquisition of all project equipment. The unit of measurement is “monetary ($)” and must be minimised / optimal. Total Spend – Materials (**7.2.2**) This metrics measures the sum of costs associated with acquisition of all project materials. The unit of measurement is “monetary ($)” and must be minimised / optimal. Percentage (%) Managed Spend – Labour , Equipment, Materials – Project (**7.2.3**) This metrics measures the percentage (%) of total Project’s spends including LEM. The unit of measurement is “numerical (%)” and comparative. Percentage (%) Managed Spend – Labour , Equipment, Materials – Area (**7.2.4**) This metrics measures the percentage (%) of each Project’s Areas spends including LEM. The unit of measurement is “numerical (%)” and comparative. Values ($) of E/M Invoices - On Hold or Blocked (**7.2.5**) Total value of On-Hold Invoices or Blocked Invoices that have been submitted under Equipment and Materials Category. The unit of measurement is “monetary” and must be minimised.

Dany Julien (2019)

Table L4. 5
Rework Spends

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
7.3	Rework Spends	7 Cost to Engineering Change Notice (Change Order / Deviation Order) **(7.3.1)** This metrics measures the cost to proceed and make change(s) following an Engineering Change Notice. This unit of measurement is "monetary ($)" and must be minimised. Cost To Non-Compliance (NCR) **(7.3.2)** This metrics measures the cost of non-compliance, including settlements and fines. This unit of measurement is "monetary ($)" and must be minimised. Cost to Rework **(7.3.3)** This metrics measures the total value ($) in hours that crews have to work due to all reworks. The unit of measurement is "monetary ($)" and must be minimised. Material Savings Contribution – Substitution Program (7.3.4) This metrics measures the value ($) of savings contribution when substituting materials or equipment during the project. The unit of measurement is "monetary ($)" and must be maximised, whenever possible.

Dany Julien (2019)

Table L4. 6
IT Integration Spends

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
7.4	IT Integration Spends	Cost, Integrate Information Technology **(7.4.1)** This metrics measures the total cost for integrating IT at site. This unit of measurement is "monetary" and must be optimal.

Dany Julien (2019)

Table L4. 7
Transportation Spends

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
8.1	Transportation Spends	Total Spends - Freight (Inbound + Outbound) (**8.1.1**) This metrics measures the total Freight cost for all material, equipment and air freight used for the Project. Paid freight and duties from point of Suppliers to Job Site. This unit of measurement is "monetary" and must be minimised. Total Spends - Expedite Freight (Inbound + Outbound) (**8.1.2**) This metrics measures the premium freight cost for Expediting delivery (Inbound and Outbound). This unit of measurement is "monetary" and must be minimised. Percentage (%) Total Spends (Expedite to Total Freight) (**8.1.3**) This ratio could indicate problems in the delivery cycle, causing premium freight shipments to meet customer delivery dates. This unit of measurement is "numerical (%)" and must be minimised. Freight rates per kg / metric tons / TEU (**8.1.4**) These metrics are used to measures various Freight rates such as $/kg; $/mt, $/TEU. This unit of measurement is "monetary" and must be minimised. Total Spends - Material / Equipment Handling (**8.1.5**) This metrics measures the total cost that a Project spends on handling / crane operations for lifting Materials / Equipment at a transload site. This metrics exclude all crane operations for Material / Equipment ready for field installation. This unit of measurement is "monetary" and must be minimised. Values ($) of Transportation Invoices - On Hold or Blocked (**8.1.6**) Total value of On-Hold Invoices or Blocked Invoices that have been submitted under Transportation Category. The unit of measurement is "monetary" and must be minimised.

Dany Julien (2019)

Table L4. 8
Customs Spends

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
8.2	Customs Spends	Spends - Customs Clearance (8.2.1) This metrics measures the cost for foreign equipment / materials to clear Customs. This unit of measurement is "monetary" and must be optimal. Values ($) of Customs Invoices - On Hold or Blocked (8.2.2) Total value of On-Hold Invoices or Blocked Invoices that have been submitted under Customs Category. The unit of measurement is "monetary" and must be minimised.

Dany Julien (2019)

Table L4. 9
Warehouse / Laydown Spends

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
8.3	Warehouse / Laydown Spends	Costs - Warehouse / Laydown Direct (8.3.1) This metrics measures the cost to maintain a warehouse + laydown at site in operations = electrical + heat + taxes + amortization. The unit of measurement is "monetary ($)" and must be minimised. Inventory Value to Warehouse Cost Ratio (8.3.2) This metrics measures the ratio of the Inventory value at site divided by the value of maintaining a warehouse in operation. The unit of measurement is "monetary ($)" and has the project approaches near the end, this ration will be "0". Values ($) of Warehouse / Laydown Invoices - On Hold or Blocked (8.3.3) Total value of On-Hold Invoices or Blocked Invoices that have been submitted under Warehouse / Laydown Category. The unit of measurement is "monetary" and must be minimised.

Dany Julien (2019)

Table L4. 10
Inventory Carrying Costs

<table>
<tr><td colspan="2">PROJECT CONTROLS
(IV)</td><td>Level I Metrics

6. Budget & Planning
7. LEM Spends
8. Logistics Spends
9. Processing Spends</td></tr>
<tr><td colspan="2">Level II Metrics</td><td>Level III Metrics</td></tr>
<tr><td>8.4</td><td>Inventory Carrying Costs</td><td>
<u>Inventory – Field Ready</u>

• <u>Inventory Value (8.4.1)</u>
This metrics measures the value of the Inventory at site, on the 1st of each month. The unit of measurement is “monetary ($)” and must be minimised.
• <u>Inventory Carrying Costs (ICC) (8.4.2)</u>
This metrics measures the Inventory Carrying Cost and its value on carrying inventory at job site, over investing it at 10%. The unit of measurement is “monetary ($)” and must be minimised. ICC = Inventory Carrying Rate (10%) x Inventory Value, on the 1st of each month

<u>Surplus Inventory</u>

• <u>Value of Surplus to Inventory (8.4.3)</u>
This metrics measures the monetary value ($) indicating the currently surplus value (inactive assets) held against the Total Inventory Value. Surplus stocks can be reused in other area of the Project or sold for auction. The unit of measurement is “monetary ($)” and must be minimised.
• <u>Surplus Inventory / Total Spend Equipment + Materials (8.4.4)</u>
This ratio measure the amount of surplus inventory in relation to the overall Project’s Spend in Equipment and Materials. The unit of measurement is “numerical (%)” and must be minimised.
• <u>Value of Obsolete Stock (8.4.5)</u>
This metrics measures the monetary value of obsolete stock - inventory items replaced by an alternative. Obsolete stocks cannot be reused for the Project but can be sold for auction. The unit of measurement is “monetary ($)” and must be minimised.

<u>Damaged Inventory</u>

• <u>Value of Damaged Inventory (8.4.6)</u>
This metric measures the monetary value ($) of Damaged Inventory at job site. Damaged materials or equipment that were returned to Suppliers are excluded in this value. The unit of measurement is “monetary ($)” and must be minimised.

<u>Sold for Auction / Recycled</u>

• <u>Cost Recovery for Materials/Equipment classified as Waste Recycled (8.4.7)</u>
This metrics measures the value ($) of sold for auction / recycling sites of materials/equipment that has become surplus / damaged / obsolete to the Project, against their book value. The unit of measurement is “monetary ($)” and must be minimised.
</td></tr>
</table>

Dany Julien (2019)

Table L4. 11
Suppliers' Spends

PROJECT CONTROLS (IV)		Level I Metrics 6. Budget & Planning 7. LEM Spends 8. Logistics Spends 9. Processing Spends
Level II Metrics		Level III Metrics
9.1	**Supplier's Spends**	Spends – All Supplier (**9.1.1**) This metrics measures the total amount ($) that are spent for all Suppliers. The unit of measurement is "monetary ($)" and comparative. Spends – Preferred Suppliers (**9.1.2**) This metrics measures the total Spends ($) allocated for Preferred Suppliers. The unit of measurement is "monetary ($)" and comparative. Percentage (%) Spent of Preferred Suppliers (**9.1.3**) The total percentage (%) of Spend that are allocated to Preferred Suppliers during a project. The unit of measurement is "numerical (%)" and comparative. Percentage (%) of Suppliers - Make-Up 80% - Spends (**9.1.4**) This metrics measures the percentage (%) of total Suppliers that are responsible for 80% of Spends. The unit of measurement is "numerical (%)" and comparative. Percentage (%) of Maverick Spend (**9.1.5**) This metrics measures the percentage (%) of Spends that is not guided by any contract sanctioned by Procurement. These purchase orders are common at job site, where delivery time is important to the Project. The unit of measurement is "numerical (%)" and must be minimised. Supplier Price Performance (**9.1.6**) This metrics intends to keep track of material price increase over yearlong Project. Supplier product / services price variance expressed as a percentage (%).The unit of measurement is "numerical (%)" and must be minimised.

Dany Julien (2019)

Table L4. 12
Purchase Order Costs

PROJECT CONTROLS (IV)		**Level I Metrics** **6. Budget & Planning** **7. LEM Spends** **8. Logistics Spends** **9. Processing Spends**
Level II Metrics		**Level III Metrics**
9.2	**Purchase Orders' Costs**	Average Cost - Purchase Order (**9.2.1**) This metrics measures the total Average Cost for processing a purchase order. The unit of measurement is "monetary ($)" and must be minimised. Average Cost - Purchase Order Change Request (**9.2.2**) This metrics measures the total Average Cost for processing a Purchase Order Change Request. The unit of measurement is "monetary ($)" and must be minimised. Average Cost – Invoice processing (**9.2.3**) This metrics measures the total Average Cost for processing a Received Invoice including: receipt, review, processing and payment of a supplier's invoice receive at site. The unit of measurement is "monetary ($)" and must be minimised.

Dany Julien (2019)

APPENDIX L5

WORKERS MANAGEMENT: LEVEL III

WORKERS MANAGEMENT: LEVEL III METRICS

Table L5. 1
Labour Force's Information

WORKERS (ASSET) MANAGEMEMT (V)		Level I Metrics 10. Workers' Information
Level II Metrics		Level III Metrics
10.1	Labour Force's Information	Male / Female (**10.1.1**) This unit record the gender of the worker. Age (**10.1.2**) This unit record the age of the worker. Education / Diploma / Certificate (**10.1.3**) This unit record the name of the degree, diploma or certificate which the worker is qualified for. Number of Years of Education (**10.1.4**) This unit record the number of years in education for each worker. Trade (**10.1.5**) This unit record the trade which the worker was hired for. Number of Trade Certification (**10.1.6**) This unit record the number of trade which the worker has received certification for. Years of expertise in working under the trade (**10.1.7**) This unit record the years of expertise, which the worker has been working under its trade. Years of expertise in construction (**10.1.8**) This unit record the total number of years, which the worker has been working in construction, in general. Province of origin for worker's union hall (**10.1.9**) This unit record the location of the union hall where the worker is assigned. Performance - Completing Work Package on-time (**10.1.10**) The unit measure the success (Yes) of each Work Package the worker has been assigned to. Performance – Failure in completing Work Package on-time (**10.1.11**) The unit measure the failure (No) of each Work Package the worker has been assigned to. WBS and Duration of Work Package (**10.1.12**) This unit record the WBS and the duration of each Work Package the worker has been assigned to. Length of rotation (**10.1.13**) This unit record the length of rotation which a worker has been assigned to.

Dany Julien (2019)

Table L5. 2
Management Information

WORKERS (ASSET) MANAGEMEMT (V)		Level I Metrics 10. Workers' Information
Level II Metrics		**Level III Metrics**
10.2	**Management Information**	Male / Female (**10.2.1**) This unit record the gender of the manager. Age (**10.2.2**) This unit record the age of the manager. Job Title (**10.2.3**) This unit record the job title of the manager. Education / Diploma / Certificate (**10.2.4**) This unit record the name of the degree, diploma or certificate which the manager is qualified for. Number of Years of Education (**10.2.5**) This unit record the number of years in education for each manager. Years of expertise in management (**10.2.6**) This unit record the years of expertise in management role – in and off construction industry. Holding a trade (**10.2.7**) This unit record if a manager holds a union trade. Years of expertise in construction (**10.2.8**) This unit record the number of year's expertise in construction management. Province of origin for manager (**10.2.9**) This unit record the location by Province, which the manager was hired from. Length of rotation (**10.2.10**) This unit record the length of rotation which a manager has been assigned to.

Dany Julien (2019)

APPENDIX L6

PROJECT COMPLEXITY: LEVEL III

PROJECT COMPLEXITY: LEVEL III METRICS

Table L6. 1
Manufacturing Complexity

PROJECT COMPLEXITY (VI)		Level I Metric : 11. Off-Site Complexity 12. Job Site Complexity
Level II Metrics		Level III Metrics
11.1	Manufacturing Complexity	Number of Suppliers Using One Manufacturing Plant (**11.1.1**) This unit measures the number of Suppliers that are fabricating their equipment/materials from one source or manufacturing plant. The unit of measurement is "numerical" and should be maximised. Number of Suppliers with Several Manufacturing Plants (**11.1.2**) This unit measures the number of Suppliers that are fabricating their equipment/materials from several sources or manufacturing plants. The unit of measurement is "numerical" and kept to a minimum.

Dany Julien (2019)

Table L6. 2
Distribution Complexity

PROJECT COMPLEXITY (VI)		Level I Metric : 11. Off-Site Complexity 12. Job Site Complexity
Level II Metrics		Level III Metrics
11.2	Distribution Complexity	Number of Material Receiving Report at Site – MRR (**11.2.1; 11.2.2; 11.2.3; 11.2.4**) This metrics measures the total number of Material Receive Report (MRR) that are received each shipment. The unit of measurement is "numerical" and comparative. • Per week, per month, per year, per Area The MRR can be accounted per Week, per Month, per Year, per Area. The unit of measurement is "numerical" and comparative. Number of Shipment From Locations (**11.2.5**) This metrics measures the number of Locations used for shipment of equipment and materials. This unit of measurement is "numerical" and should be kept to a minimum. Number of Off-site Warehouse / Laydown (**11.2.6**) This metrics measures the number of Warehouse / Laydown used Off-Site, for equipment/materials in waiting to be shipped to a job site. The unit of measurement is "numerical" and should be minimised. Number of Transportation Carriers (**11.2.7**) This metrics measures the number of Transportation Carriers hired for the Project. The unit of measurement is "numerical" and should be kept to a minimum. Number of Freight Forwarders (**11.2.8**) This metrics measures the number of Freight Forwarders hired for the Project. The unit of measurement is "numerical" and should be kept to a minimum. Number of Customs Brokers (**11.2.9**) This metrics measures the number of Customs Brokers hired for the Project. The unit of measurement is "numerical" and should be kept to a minimum.

Dany Julien (2019)

Table L6. 3
Suppliers Base Complexity

PROJECT COMPLEXITY (VI)		**Level I Metric :** **11. Off-Site Complexity** **12. Job Site Complexity**
Level II Metrics		**Level III Metrics**
11.3	**Suppliers Base Complexity**	Number of Suppliers –Project (**11.3.1**) This metrics measures the total number of Suppliers, including preferred and regular suppliers for the Project. The unit of measurement is “numerical” and should be optimal. Number of Preferred Suppliers (**11.3.2**) This metrics measures the total number of selected Preferred Suppliers for the Project. The unit of measurement is “numerical” and should be optimal. Sole Source Supplier (**11.3.3**) This metrics measures the number of Sole Source Supplier. The unit of measurement is “numerical” and comparative.

Dany Julien (2019)

Table L6. 4
IT Base Complexity

<table>
<tr><th colspan="2">PROJECT COMPLEXITY (VI)</th><th>Level I Metric :

11. Off-Site Complexity
12. Job Site Complexity</th></tr>
<tr><th colspan="2">Level II Metrics</th><th>Level III Metrics</th></tr>
<tr><td>11.4</td><td>IT Base Complexity</td><td><u>Procurement</u>

• <u>Number of Suppliers with e-Procurement Enabled (11.4.1)</u>
This metrics measures the number of Suppliers that are linked the Project's ERP integrated system. The unit of measurement is "numerical" and should be maximised.

• <u>Percentage (%) of Suppliers with e-Procurement Enabled</u> (11.4.2)
This metrics measures the percentage (%) of Suppliers that are linked to the Project's ERP integrated system. The unit of measurement is numerical (%) and should be maximised.

Engineering
• <u>Integrated Construction Modeling System (11.4.3</u>)
This metrics measures if Engineering firms, located at job site, operate on a single integrated construction modeling system. An integrated model system would comprise the following activities: Procurement, Engineering, Construction, Cost Control, Planning, and Scheduling). The unit of measurement is "Yes/No".

Construction

• <u>Integrated Construction Modeling System (11.4.4</u>)
This metrics measures if Contractors, located at job site, operate on a single integrated construction modeling system. An integrated model system would comprise the following activities: Procurement, Engineering, Construction, Cost Control, Planning, and Scheduling). The unit of measurement is "Yes/No".

Management

• <u>Integrated Construction Modeling System (11.4.5</u>)
This metrics measures if Corporate / Construction Management Teams, located at job site, operate on a single integrated construction modeling system. An integrated model system would comprise the following activities: Procurement, Engineering, Construction, Cost Control, Planning, and Scheduling). The unit of measurement is "Yes/No".</td></tr>
</table>

Dany Julien (2019)

Table L6. 5
Contractor Base Complexity

PROJECT COMPLEXITY (VI)		**Level I Metric :** **11. Off-Site Complexity** **12. Job Site Complexity**
Level II Metrics		**Level III Metrics**
12.1	**Contractor Base Complexity**	Number of Contractors At Site – Weekly (**12.1.1**) This metrics measures the Weekly number of Contractors (companies) at Job Site. The unit of measurement is "numerical" and should be optimal. Number of Contractors At Site – Project (**12.1.2**) This metrics measures the total number of Contractors (companies) that have worked at job site since Day 1. The unit of measurement is "numerical" and should be optimal. Number of Management Staffs (Contractors) At Site – (Day/Night + Weekly / Monthly / Project) (**12.1.3; 12.1.4; 12.1.5; 12.1.6**) This metrics measures the total number of Contractors' Management Staffs at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. Number of Labour Workers (Contractors) At Site – (Day/Night + Weekly / Monthly / Project) (**12.1.7; 12.1.8; 12.1.9; 12.1.10**) This metrics measures the total number of Contractors' Labour Workers at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. Percentage (%) of Contractors' Management Staffs To Labour Workers At Site – (Day/Night + Weekly / Monthly / Project) (**12.1.11; 12.1.12; 12.1.13; 12.1.14**) This metrics measures the percentage (%) of the total number of Contractors' Management Staff divided by the total number of Contractors' Labor Workers at Job Site. Measurement are taken for the Day and Night shifts, as well as weekly, monthly and cumulative for the Project. The unit of measurement is "numerical (%)" and should be minimised. Number of Foreman at Site (Day/Night + Weekly / Monthly/ project) (**12.1.15; 12.1.16; 12.1.17; 12.1.18**) This metrics measures the total number of Contractors' Foreman at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. Number of General Foreman at Site (Day/Night + Weekly / Monthly) (**12.1.19; 12.1.20; 12.1.21; 12.1.22**) This metrics measures the total number of Contractors' General Foreman at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal.

12.1	**Contractor Base Complexity**	<u>Number of Superintendent at Site (Day/Night +Weekly / Monthly) **(12.1.23; 12.1.24; 12.1.25; 12.1.26)**</u> This metrics measures the total number of Contractors' Superintendent at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. <u>Number of Trades At Site (Weekly / Monthly / Project) **(12.1.27; 12.1.28; 12.1.29; 12.1.30)**</u> This metrics measures the total number of Trades At Site. Measurement are taken weekly and monthly and cumulative for the Project. • <u>Number of Labour Workers - Civil Trades – (Day Shift + Night Shift) + (Weekly / Monthly / Project) **(12.1.31; 12.1.32; 12.1.33; 12.1.34)**</u> This metrics measures the total number of Contractors' Civil Trades at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. • <u>Number of Labour Workers - Structural & Architectural Trades – (Day Shift + Night Shift) + (Weekly / Monthly / Project) **(12.1.35; 12.1.36; 12.1.37; 12.1.38)**</u> This metrics measures the total number of Contractors' Structural & Architectural Trades at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. • <u>Number of Labour Workers - Mechanical & Piping – (Day Shift + Night Shift) + (Weekly / Monthly / Project) **(12.1.39; 12.1.40; 12.1.41; 12.1.42)**</u> This metrics measures the total number of Contractors' Mechanical & Piping Trades at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. • <u>Number of Labour Workers - Electrical & Mechanical – (Day Shift + Night Shift) + (Weekly / Monthly / Project) **(12.1.43; 12.1.44; 12.1.45; 12.1.46)**</u> This metrics measures the total number of Contractors' Electrical & Instrumentation Trades at Job Site that are assigned the Day Shift or Night Shift. Measurements are taken weekly, monthly and cumulative for the Project. The unit of measurement is "numerical" and should be optimal. <u>Number of Area of Under Construction **(12.1.47)**</u> This metrics measures the number of Area under Construction at Job Site. The unit of measurement is "numerical" and should be optimal.

Dany Julien (2019)

Table L6. 6
Management Team / Owner Representative

PROJECT COMPLEXITY (VI)		Level I Metric : 11. Off-Site Complexity 12. Job Site Complexity
Level II Metrics		Level III Metrics
12.2	Management Team / Owner Representatives	Number of Corporate Management Staffs At Site (Day Shift + Night Shift) + (Weekly / Monthly) **(12.2.41; 12.2.2; 12.2.3; 12.2.4)** This metrics measures the number of Corporate Management Staffs at Job Site. Measurements are taken weekly, monthly and for the Day and Night shifts. The unit of measurement is "numerical" and should be optimal. Number of Corporate Management Staffs Off-Site **(12.2.5)** This metrics measures the number of Corporate Management Staffs assigned to the Project, however, staffs remain off-site. The unit of measurement is "numerical" and should be optimal. Number of Construction Management Team (Owner Representatives) At Site Day Shift + Night Shift) + (Weekly / Monthly) **(12.2.6; 12.2.7; 12.2.8; 12.2.9)** This metrics measures the number of Construction Management Staffs at Job Site. Measurements are taken weekly, monthly and for the Day and Night shifts. The unit of measurement is "numerical" and should be optimal. Number of Consultants (Owner Representatives) At Site Day Shift + Night Shift) + (Weekly / Monthly) **(12.2.10; 12.2.11; 12.2.12; 12.2.13)** This metrics measures the number of Consultant (Owners Rep) at Job Site. Measurements are taken weekly, monthly and for the Day and Night shifts. The unit of measurement is "numerical" and should be optimal.

Dany Julien (2019)

APPENDIX L7

PERFORMANCE ANALYTICS: LEVEL III

PERFORMANCE ANALYTICS: LEVEL III METRICS

Table L7. 1
Performance Analytics

PROJECT COMPLEXITY (VI)		**Level I Metric :** **13. Performance Analytics**
Level II Metrics		**Level III Metrics**
13.1	**Performance Analytics**	Performance Analytics with Level II Metrics (**13.1.1**) This unit considers using analytical tools with Level II metrics. Performance Analytics with Level III Metrics (**13.1.2**) This unit considers using analytical tools with Level II metrics.

Dany Julien (2019)

GLOSSARY

Acfas – An acronym for the Association canadienne-française pour l'avancement des sciences. Part of the process validation in a Design-Science Research is to meet four (4) basic phases: Analysis, Design, Evaluation and Diffusion. Hence the researcher will proceed with a diffusion of its research at the *Congrès de l'Association canadienne-française po pour l'avancement des sciences (Afcsa)*, in Gatineau, Québec, between 27th and 31st May 2019.

CAPEX – An acronym for Capital Expenditure. These capital expenditures are funds used by a company to undertake new projects, upgrade or maintain current assets such as machineries and building.

COAA / CII – An acronym for Construction Owner Association of Alberta and Construction Industry Institute. Both groups gravitate towards providing best practices in the construction industry in Canada and the United States of America, including leadership to enable the construction industries in both countries to drive for a safe, effective, timely and productive project execution.

CPM – An acronym for Construction Project Management - A terminology which explains the management of construction project, which requires knowledge of business management as well as the understanding of the design and construction process. CPM includes the following phases: a) Conceptual, b) Front-End Planning, c) Detailed Engineering, d) Construction, and e) Closed-out.

CPPM – An acronym for Construction Performance & Productivity Model. This design is in fact the artifact proposed in the paradigm of the Design Science Research. It contains performance attributes and related metrics pertinent to construction. The framework of the CPPM is based on the SCOR Model.

EPC – An acronym for Engineering, Procurement, and Construction. EPC is a contracting agreement used in the engineering and construction industries. The engineering and construction companies, often the same one, will execute the detailed design, procure all the equipment and materials, and construct to deliver the project.

EPCM – An acronym for Engineering, Procurement and Construction Management. In this case, the engineering firm will execute the detailed design, procure the long lead items and is responsible for administering the construction contracts and the various contractors involved in delivering the project.

KPI – An acronym for Key Performance Indicator. The CPPM design measures construction performance (quantity, time, frequency, and ratio) and labour productivity (output volume / labour input use) and cost effectiveness through a series of Level I, II and III metrics.

OPEX – An acronym for Operating Expenses and represent costs to maintain a business in operations, such as transport, electricity, rent, salaries, property taxes, etc.

Performance Attributes – The SCOR Model's performance attributes measure whether a process is being managed effectively, and whether a customer's need is being met. The model has five attributes: a) reliability, b) responsiveness, c) agility, d) costs, and e) asset management. The CPPM artifact has six attributes: a) procurement reliability, b) procurement responsiveness, c) EPCM agility, d) project control, e) workers management, f) project complexity and g) project integrity.

PMBOK – An acronym for Project Management Body of Knowledge. PMBOK is a collection of processes, best practices, terminologies and guidelines that are accepted as standards within the PMI.

PMI – An acronym for Project Management Institute. It is a global leader in project management certifications that promotes the application of knowledge, skills, tools and techniques to project activities and requirements.

SCOR Model – An acronym for Supply Chain Operational Reference Model. The SCOR Model is a management tool used to improve supply chain management decisions within an organization's operation and with its suppliers and customers. The model assists the users with the processes along the entire supply chain and provide a basis to improve those processes.

Robustness Value – The CPPM artifact measures level of robustness for each Level I, II, and III metrics pertaining to specific performance attributes. The measurement of robustness is based on results obtained with a Likert scale made by the participants. Level III metrics are a combination of score obtained from performance attributes, Level I and II metrics. These robustness metrics are the components of the robustness value.

INDEX